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AC/243(Panel 7)TR/6

EVALUATION READINESS AND SUSTAINMENT POLICY

Final Report

Panel 7 on the Defence Applications of Operational Research

Specialist Team 3 on Readiness and Sustainment

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14. Abstract:
The Specialist Team (ST) 3 on the Evaluation of Readiness and Sustainment Policy was set up by the DRG Panel 7 in January 1994 on the recommendation of the findings of the Exploratory Group (EG) on R&S Analyses. The ST was tasked to review and share existing approaches and then to recommend and develop methodologies to assist policy makers and planners. The focus was to be on two key problems: (1) flexible readiness to assist cost trade-off between peacetime options and transition to maritime readiness; (2) joint readiness to assess economies of joint multinational and coalition forces. This report addresses readiness evaluation from the point of view of capability generation. The main components of the problem are time evaluation and resource allocation subject to achieving benchmarks of oeprational capability standards.

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TECHNICAL REPORT
AC/243(Panel 7)TR/6

DEFENCE RESEARCH GROUP
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PANEL 7 ON THE DEFENCE APPLICATIONS OF OPERATIONAL RESEARCH

Technical Report on Evaluation of Readiness and Sustainment Policy

1. This is the Technical Report on Evaluation of Readiness and Sustainment Policy - Final Report - prepared by the Specialist Team 3 on the same subject, under Panel 7 on the Defence Applications of Operational Research.

2. The Executive Summary ("Yellow Pages") has been issued under reference AC/243-N/479, dated 3 February 1997.

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EXECUTIVE SUMMARY

INTRODUCTION

i. The current decade has seen significant changes in world order. For military planners, the end of the Cold War has brought about a need to re-think the principles, methods and objectives of military planning. The evaluation of threats and the subsequent identification of military capability requirements, is much less clear-cut than it was only ten years ago. Forces that were designed and assembled during the Cold War era must now be realigned and modernised in the new order. Consequently, planners must assess a broad spectrum of options for rationalising and re-designing armed forces that are suitable for coping with a greater diversity of potential conflict. The broad spectrum of options includes greater latitude for varying the response time of capability generation for operations, depending upon the potential requirements.

ii. During the Cold War, nations were willing to accept relatively high investment in military procurement in return for reasonable assurance of adequate threat deterrence. The end of the Cold War, however, has brought the perception that direct military threats have either subsided or largely disappeared and with that has come a more relaxed attitude toward deterrence. With the end of the "war", the term "peace dividend" has been coined in reference to potential budgetary savings from reduced spending on military capability. Economic considerations add a further dimension to the military planning problem.

iii. Quite apart from operational effectiveness considerations, governments of most western nations are motivated by economic pressures to glean greater efficiency from spending and taxation. As a consequence, many nations are examining their defence investments with the goal of making reductions wherever possible. In this climate, the realignment and rationalisation of forces, for some nations, is subject mainly to budgetary pressures.

GENERAL APPROACH

iv. The Specialist Team (ST) on the Evaluation of Readiness and Sustainment Policy was approved by NATO Panel 7 in January 1994 on the recommendation of the findings of the Exploratory Group (EG) on R&S Analysis. The work of the ST commenced in April 1994 and concluded in January 1996.

v. The ST was tasked to review and share existing approaches and then to recommend and develop methodologies to assist policy makers and planners. The focus was to

be on two key problems: (1) flexible readiness - to assess cost trade-offs between peacetime options and transition to wartime readiness; (2) joint readiness - to assess economies of joint, multi-national and coalition forces.

vi. During a 24 month time frame, the ST was directed to aim at: sharing data sets and existing methodologies; deriving Cost Estimating Relationships (CER) and models to establish viable peacetime readiness; identifying gaps in existing methods; examining national level methods to assess flexible readiness; deriving an integration process and methodology to assess joint readiness; and developing a research action plan to support recommended methodologies.

vii. The report addresses readiness evaluation from the point of view of capability generation. The main components of the problem are time evaluation, and resource allocation subject to achieving benchmarks for operational capability standards. An activity-based methodology is described which allows Resource-Constrained Critical Path Analysis (CPA) and Activity-Based Costing (ABC) to be applied to readiness evaluation.

A READINESS PARADIGM

viii. The process of force generation can be described by a generic paradigm:

- strategic assessment determines the size of the force to be raised, its composition, the expected duration of the conflict, the level of intensity, the theatre of operations and the required response time;
- from this follow the operational capabilities, tasks and mission elements that are required to be generated along with the numbers of units required and the resources that they will need to mount sufficient response to the threat;
- training requirements and other preparations that must be made at the level of individual units are determined;
- joint preparations and joint training requirements for groupings of units are identified;
- movement requirements for training and deployment of units into the theatre of operations is assessed.

ix. Having identified capability requirements, and the types of units that can provide the capabilities, matrix views of preparation and transportation activities can be generated that record both time and cost for each activity. By summing over the units, an estimate for the total time and the total cost for each unit can be made. Such estimates must

be treated with caution, however, because they do not take into account precedence relationships and resource-constraints, which can induce delays.

x. However, it is reasonable to expect that the summation estimates are approximately proportional to the actual values. As a consequence, relative comparisons of summation estimates are valid and hence, the screening of attractive options for minimum response time forces and minimum cost forces using summation estimates is not unreasonable. Attractive options can subsequently be analysed more carefully using resource-constrained critical path analysis (R-C CPA) and activity-based costing (ABC).

FRAMEWORK FOR READINESS EVALUATION

xi. Military objectives consist of tasks that will be assigned to a formation consisting of a set of military units. A set of "benchmarks" is given which the formation must meet, as a whole, in order to be rated as "ready" to undertake the objective. Some of the benchmarks may involve single units only, while others may involve joint preparations, e.g. joint training.

xii. Target values for the benchmarks might be arrived at by operational analysis or they might be given based upon military judgement and experience. However, they must be given in quantitative terms in such a way that a quantitative method such as R-C CPA can be used to determine the length of time required to achieve them. Again, the "benchmarks" might include target values for any or all of the "attributes" under consideration thereby allowing a direct link between attributes and readiness.

xiii. The problem of evaluating readiness then becomes a problem of deriving timings to achieve individual benchmarks, identifying resource constraints and establishing precedence relationships among the constituent activities so that R-C CPA can be used to determine the time required for the formation as a whole to achieve all of the benchmarks.

xiv. By relating time to benchmarks and attributes, a refined definition of readiness can be given which generalises the unit level definition and includes the definition of operational readiness:

given a set of units, and for each unit and every unit, a set of target values for benchmarks of personnel, training, logistic support, equipment and command & control:

readiness is defined as the time required to perform a set of activities that brings the benchmarks to the target values for each unit.

xv. Consider that joint readiness can be addressed by this definition. For joint readiness, the units are simply those units which make up the proposed joint force; the activities will be taken as the proposed force generation activities for the operation; the benchmarks and their target values are chosen appropriately according to measures of effectiveness for the proposed joint operation.

xvi. Furthermore, flexible readiness can be addressed by this definition. Note that the definition places no specifications on the "activities" other than the requirement that they raise the benchmark values to the given target values. As well, no specifications are given for the initial values of the benchmarks. Thus, there is considerable "flexibility" for the activities and the units that are brought into the readiness evaluation framework. As long as some timing relationship exits between the activities and the benchmarks for the given set of units then readiness of the units can be evaluated.

xvii. The framework allows risk analysis to be included in terms of sensitivity analysis with respect to changes in resources, timing and activities.

READINESS ESTIMATION METHODOLOGY

xviii. Military capabilities result from the proper synchronisation and co-ordination of tasks and mission elements of military units; in general, tasks and mission elements can be described by activities that have resource requirements, precedence relationships and performance standards.

xix. Processes consume resources; so readiness generation involves resources that are directly related to the capabilities they effect but also resources that are used by the process itself (*e.g.* some training will use ammunition over and above that which is the prescribed allotment for actual combat).

xx. Military commanders must use time and resources to generate and employ military capability in order to achieve military objectives. R-C CPA provides a very broad and a very powerful analytical tool to evaluate timing and resource requirements of a general nature. Typically, however, R-C CPA is not sufficient to carry out all of the resource allocation required to optimise an application. In such cases, resource allocation sub-problems can be formulated and solved by special-purpose sub-methods.

xxi. Low cost software is available "off the shelf" to implement the R-C CPA methodology. Experiments with SYMANTEC◆ TIMELINE® have demonstrated the potential utility of such software.

COST ESTIMATION OF READINESS OPTIONS

xxii. Managers of defence departments and armed forces are motivated to reduce budgets and to glean greater efficiency from spending on military capability. The art and science of cost estimation is of importance because it provides the basis for investigating ways of becoming more efficient. By exploring cause and effect relationships in spending patterns, managers can improve the return on public money invested in military capability.

xxiii. More specifically, cost estimation of readiness options is of interest since cost estimation can provide a means for identifying areas of potential cost reductions. For example, reduction in the cost of operations and maintenance, training, logistic support and infrastructure might be derived from judicious cost analysis of readiness options.

Activity-Based Costing

xxiv. Intuitively, an "activity" is something that must be done in order to accomplish an objective. In corporate circles, an "activity" describes the way an enterprise employs its time and resources in order to achieve corporate objectives. In technologically advanced organisations, it is economically valuable to model cost effectiveness in terms of activities because traditional accounting methods fail to correctly attribute the relative value of human resources to specific "outputs" in organisations where technology contributes significantly and in varying degrees to the outputs. A greater proportion of indirect costs (overhead) including technology costs and information processing costs now contributes more to the total cost of maintaining and deploying armed forces than it ever did before. For this reason, many defence departments are moving toward ABC.

xxv. Beyond the issue of attributing overhead costs to outputs, ABC provides a means to relate performance measures for activities at each stage of a process to the ultimate outputs and thereby to enable programs for continuous improvement of processes. A resource and activity-based model of an organisations' inputs, processes and outputs provides a means of predicting future consequences of decisions. In this context, if the "output" is taken as capability within a given response time, then ABC is a useful tool for analysing the cost effectiveness of readiness-related processes and decision-making in defence organisations.

xxvi. Activities currently form the foundation of many cost management systems as businesses and government organisations are moving toward activity-based costing. Successful implementation of activity-based costing has helped various organisations to improve their work processes, to identify cost drivers and to control costs. Moreover, implementation of activity-based costing has given managers the information they need to improve their operational and strategic decision making.

xxvii. In the public sector, it is useful to define an activity as "an element of work which turns resources into outputs". In the context of readiness evaluation, it is natural to describe both steady-state capability maintenance processes and capability surge processes in terms of "activities" where "outputs" are defined military capabilities that satisfy prescribed task standards.

xxviii. Activity-based cost analysis can be used to identify any parts of operational or support processes that do not add value to a final product. For costing readiness options, ABC can be used to analyse the cost of maintaining and surging capabilities and consequently to provide knowledge of where and how resources are being consumed. Current or proposed consumption of resources can then be rated against planning priorities and adjustments can be made to improve the effectiveness of budgetary allocations.

xxix. Policy measures that change activity rates or resource capacities will have a significant impact on readiness both from a time and cost point of view. A policy measure can have impact on activity rates and resource capacities both during the steady state and during surge periods. Changes in activity rates and changes in resource capacities will cause changes in the length of surge periods, as well as changes in capability maintenance activities during the steady state.

xxx. Typical readiness options take the form of resource or activity trade-offs. Managers are motivated to find innovative ways of achieving the same or improved readiness standards while using the same or lower levels of resources. In many cases, the cost of using internal resources to provide a service must be compared to the cost of contracting out; or the cost of purchasing equipment or constructing a building must be compared to the cost of leasing comparable equipment or facilities. Transportation and training options are other areas of potential cost reduction.

xxxi. Intuitively one expects that lower readiness requirements should lead to lower defence spending. The principal means by which spending would be lowered is by scaling down operations. That is, fewer facilities, fewer personnel, lower resource consumption, lower maintenance levels, lower training levels should lead to lower O&M costs and lower overhead costs. The trade-off however, would be longer readiness times and lower steady state capability. Nevertheless, it might be that for some readiness situations, getting ready faster would actually save money. That is, R-C CPA might reveal ways of getting things done more efficiently in such a way that time saved is proportional to money saved. In any case, the methodology of R-C CPA can be applied to existing plans to test their feasibility and efficiency and can in many cases reveal more efficient ways of accomplishing readiness.

MILITARY BENEFITS

xxxii. The ST reports a number of military benefits. The work of the ST has put forward a comprehensive methodology for :

- **cost effectiveness studies:**

  the use of activity-based costing coupled with R-C CPA enables careful assessment of the cost effectiveness of readiness alternatives and policy options;

- **readiness evaluation:**

  R-C CPA enables careful analysis of response time and benchmarking for readiness; it provides a basis for testing and validating timing estimates as well as estimates for resource requirements;

- **policy evaluation:**

  the proposed methodology can be applied parametrically across a spectrum of scenarios in order to evaluate policy options;

- **cost/time trade-off analysis:**

  the relative worth of options in terms of response time and cost can be evaluated using R-C CPA and ABC; attractive options can be screened using the summation estimate spreadsheet;

- **resource management:**

  the methodology supports careful analysis of resource requirements and expected resource utilisation by specific activities; this enables a predictive approach to resource management which can be used to improve the efficiency of budgetary spending

ENUMERATION OF MAIN POINTS

i. The ST provides a list of its main findings:

- **refined definition of readiness:**

  the ST put forward a "refined" definition of readiness that is consistent with existing NATO definitions of readiness-related terminology but which is quantifiable enough to form the basis of methodology to evaluate readiness;

  definitions for joint readiness and flexible readiness follow in a logical and consistent way from the refined definition.

- **readiness paradigm:**

  a generic force generation process was put forward as a useful basis for deriving methodology;

- **spreadsheet estimation of time and cost:**

  using the paradigm, a spreadsheet was designed for calculating summation estimates for the response time and cost of readiness options;

  of themselves, such estimates are coarse, however, they can be used comparatively to rank the relative worth of options;

  they can be used to screen attractive options for readiness that merit more careful analysis;

  the paradigm points to the need to include transit time for joint training into the response time;

- **readiness framework:**

an activity and benchmark oriented framework for readiness evaluation was derived by generalising from principles of unit level readiness to readiness of a formation;

the framework focuses on response time as the primary measure of readiness but allows other indicators of readiness to be linked to time by means of benchmarks;

the framework supports analysis of readiness in terms of analysis of resource / time / activity requirements to achieve benchmarks within evaluated response time;

- **risk analysis:**

the framework supports risk analysis as sensitivity analysis with respect to resource / time / activity changes;

- **readiness evaluation:**

the ST proposes the use of resource-constrained critical path analysis as the basis for readiness evaluation;

relatively low cost software is available for implementing R-C CPA;

the ST recognises that R-C CPA alone is not sufficient to optimise all of the resource allocation sub-problems inherent in military readiness;

resource allocation sub-problems can be dealt with by suitable sub-procedures within the overall readiness framework subject to the umbrella R-C CPA methodology;

the ST recognises that the algorithmic complexity of R-C CPA may render it impractical for large problems, where "large" might not be adequate to address some actual situations;

however, by the tactic of optimising tractable sub-problems and aggregating outcomes from optimised sub-problems into larger problems, a good estimate for the optimal solution can be found;

furthermore, by finding an appropriate level of detail to describe activities, a manageable scale can be brought to readiness assessment problems;

- **cost estimation:**

use of activity-based costing fits naturally into the readiness evaluation framework;

activity-based costing enables direct cost relationships to be drawn between resources and capabilities by means of activity-oriented descriptions of force generation processes;

the relationship between policy and cost can be established by analysing the impact of policy decisions on steady state capacity and surge capacity;

as a general principle, cost reductions are achieved by lowering activity rates or lowering resource capacities;

R-C CPA can be used to find ways of achieving benchmarks more efficiently thereby allowing fixed readiness standards to be maintained and surged at lower cost.

OUTLINE OF CHAPTERS

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1. The current decade has seen significant changes in world order. For military planners, the end of the Cold War has brought about a need to re-think the principles, methods and objectives of military planning. The evaluation of threats and the subsequent identification of military capability requirements, is much less clear-cut than it was only ten years ago. Forces that were designed and assembled during the Cold War era must now be realigned and modernised in the new order. Consequently, planners must assess a broad spectrum of options for rationalising and re-designing armed forces that are suitable for coping with a greater diversity of potential conflict. The broad spectrum of options includes greater latitude for varying the response time of capability generation for operations, depending upon the potential requirements.

2. During the Cold War, nations were willing to accept relatively high investment in military procurement in return for reasonable assurance of adequate threat deterrence. The end of the Cold War, however, has brought the perception that direct military threats have either subsided or largely disappeared and with that has come a more relaxed attitude toward deterrence. With the end of the "war", the term "peace dividend" has been coined in reference to potential budgetary savings from reduced spending on military capability. Economic considerations add a further dimension to the military planning problem.

3. Quite apart from operational effectiveness considerations, governments of most western nations are motivated by economic pressures to glean greater efficiency from spending and taxation. As a consequence, many nations are examining their defence investments with the goal of making reductions wherever possible. In this climate, the realignment and rationalisation of forces, for some nations, is subject mainly to budgetary pressures.

1.2 TERMS OF REFERENCE

4. The Specialist Team (ST) on the Evaluation of Readiness and Sustainment Policy was approved by NATO Panel 7 in January 1994 on the recommendation of the findings of the Exploratory Group (EG) on R&S Analysis. The work of the ST commenced in April 1994 and concluded in January 1996. The following terms of reference were put forward by the EG and accepted by the ST. The unabridged terms of reference are given in Annex I.

5. The changing role of military force is driving reviews of policies for Readiness and Sustainment (R&S). Nations must now anticipate a blend of changing low and mid intensity situations in addition to the possibility of protracted conventional high intensity conflict. Planning methodologies are required that can quantify future force R&S options and identify the most cost effective options. The Exploratory Group (EG) identified gaps in methodologies for R&S assessment as well as the pressing need for higher management to evaluate trade-off analyses. As recommended in the EG meeting report, the Ad Hoc Working Group (ST) focused on flexible readiness and joint readiness.

6. The ST was tasked to review and share existing approaches and then to recommend and develop methodologies to assist policy makers and planners. The focus was to be on two key problems: (1) flexible readiness - to assess cost trade-offs between peacetime options and transition to wartime readiness; (2) joint readiness - to assess economies of joint, multi-national and coalition forces.

7. Over a 24 month time frame, the ST was directed to aim at:

- sharing data sets and existing methodologies;
- deriving Cost Estimating Relationships (CER) and models to establish viable peacetime readiness;
- identifying gaps in existing methods;
- examining national level methods to assess flexible readiness;
- deriving an integration process and methodology to assess joint readiness;

and

- developing a research action plan to support recommended methodologies.

1.4 TERMINOLOGY

1.4.1 Issues

8. For purposes of conducting a study of quantitative methods for evaluating readiness and readiness policy, NATO definitions are less than ideal in terms of logic and consistency. For example NATO MC 55/3, [Reference 22], defines unit level readiness as the *time* within which a unit can be made ready to perform unit type tasks. In contrast, operational readiness is defined in terms of *capability*. According to NATO AAP-6, [Reference 23], operational readiness is the capability of a unit/formation, ship, weapon system or equipment to perform the missions or functions for which it is organised or designed. Furthermore, the term operational readiness may be used in a general sense or used to express a level or degree of readiness.

9. Aside from the lack of rigour in NATO definitions, the ST members agreed that specific national level readiness evaluation requirements should be considered, as far as it was practical to do so. Thus, the members felt it important to consider national level readiness definitions as well from all of the nations participating in the ST so that methodology could be devised or adapted, if appropriate additions or amendments could be accomplished without undue additional work.

10. Discussions by the ST determined that notions of both time and capability are common to national level definitions of readiness in the participating nations. The ST resolved to formulate a definition of readiness that would encompass national level definitions as well as appropriate definitions for *joint* readiness and *flexible* readiness.

1.4.2 Recommendations

11. To serve the purposes of methodology and quantitative modelling, the ST members agreed on the following:

- to refine existing definitions wherever possible rather than introduce new words;

- to define any terms which are as yet undefined by NATO such as *joint* readiness and *flexible* readiness;
- never to corrupt or contradict existing NATO definitions;
- to avoid using ambiguous terms, wherever possible, even though they might have a NATO definition.

1.4.3 Working Definitions

12. The following definitions have been taken from NATO AAP-6(S) [Reference 23]. These terms either appear in the sequel or have been included as background information because they frequently appear in discussions of readiness-related matters. The terms are categorised according to four headings: force structure, force employment, readiness and capability.

13. The following terms are terms related to force structure:

unit

i. Any military element whose structure is prescribed by competent authority, such as a table of organisation and equipment; specifically, part of an organisation.

ii. An organisation title of a subdivision of a group in a task force.

iii. A standard or basic quantity into which an item of supply is divided, issued, or used. In this meaning, it is also called "unit of issue".

task force

i. A temporary grouping of units, under one commander, formed for the purpose of carrying out a specific operation or mission.

ii. Semi-permanent organisation of units, under one commander, formed for the purpose of carrying out a continuing specific task.

A component of a fleet organised by the commander of a task fleet or higher authority for the accomplishment of a specific task or tasks.

14. The following terms are terms related to force employment:

operation

A military action or the carrying out of a strategic, tactical, service, training, or administrative military mission; the process of carrying on combat, including movement, supply, attack, defence and manoeuvres needed to gain the objectives of any battle or campaign.

mission

i. A clear, concise statement of the task of the command and its purpose;

ii. One or more aircraft ordered to accomplish one particular task.

tasking

The process of translating the allocation into orders, and passing these orders to the units involved. Each order normally contains sufficient detailed instructions to enable the executing agency to accomplish the mission successfully.

mobilisation

i. The act of preparing for war or other emergencies through assembling and organising national resources.

The process by which the armed forces or part of them are brought to a state of readiness for war or other national emergency. This includes assembling and organising personnel, supplies, and material for active military service.

15. The following terms are related directly readiness:

unit readiness

Readiness of a unit is considered to be the time within which a unit can be made ready to perform unit type tasks and is amplified by indicators of its current personnel, materiel, and training state. This time does not include any transit time.

operational readiness

The capability of a unit/formation, ship, weapon system or equipment to perform the missions or functions for which it is organised or designed. May be used in a general sense or to express a level or degree of readiness.

operational readiness evaluation

An evaluation of the operational capability and effectiveness of a unit or any portion thereof.

defence readiness condition (or state of readiness)

A number or code word indicating the readiness posture of a unit for actual operations or exercises. Also called state of readiness .

immediate operational readiness

The state in which an armed force is ready in all respects for instant combat.

combat ready (or combat readiness)

i. As applied to organisation or equipment: available for combat operations;

ii. As applied to personnel: qualified to carry out combat operations in the unit to which they are assigned.

16. The following term is related to military capability:

military requirement

An established need justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions, or tasks.

1.5 GENERAL APPROACH

17. Inherent in the assessment of military capability requirements, is the need to evaluate the time and resource requirements for force generation. Methodology is needed to analyse force generation processes against the resources and infrastructure allocated to accomplish stated objectives. If nations and alliances are to evaluate force generation timings rigorously, it is essential that planners can competently evaluate the ability of their armed forces to meet prescribed timings by drawing upon the targeted resources at planned levels. To prescribe appropriate response times for capabilities and to determine the resource requirements that make the resultant capability generation process practicable, is a considerable challenge to military planners. Methodology is needed to assist planners with identifying and evaluating trade-offs between time, resources, force generation processes and monetary cost.

18. This report will address readiness evaluation from the point of view of capability generation. The main components of the problem are time evaluation, and resource allocation subject to achieving benchmarks for standards of capability. An activity-based methodology will be described which allows Critical Path Analysis (CPA) and Activity-Based Costing (ABC) to be applied to readiness evaluation.

19. The main issues considered in devising methodology were:

- the need to evaluate force generation timings with accuracy and reasonable assurance of achieving predicted capability milestones;
- the joint and combined nature of operations calls for more sophisticated methods to predict capability generation than those previously applied;
- the need to include resource requirements and resource constraints (including personnel and infrastructure) in readiness evaluation methodology;
- the need to identify economical readiness options and to harmonise with "business planning" principles currently being adapted to defence planning in many nations;
- need to allow greater flexibility in force generation processes because:
    - i. not all units are required to be at prescribed operational readiness levels all the time;

ii. there may be alternative ways to generate equivalent capabilities;

iii. units can be assigned varying readiness levels for each of their tasks or mission elements;

iv. the readiness generation process itself might be adapted as required for each operation;

v. in many nations currently, operations are of a "composite" nature (i.e. made up of parts of units) and these operations must be planned in a highly flexible and dynamic way;

- the need for risk analysis of timings, resource allocations and process feasibility in order to provide a quantifiable assurance level of predictions by the methodology.

1.6 STRUCTURE OF THE REPORT

20. The remainder of the report is structured as follows. Current methods of evaluating readiness will be described in Chapter 2. An outstanding summary of readiness evaluation methods and their deficiencies published by the RAND Corporation, is summarised there[1]. Chapter 3 is a survey of readiness evaluation requirements at the national level. This is followed by a description of NATO alliance level requirements in Chapter 4. A framework for dealing with readiness evaluation is given in Chapter 5 together with a refined definition of readiness; these form the basis of methodology. Chapter 6 presents a paradigm of the force generation process including training at both the unit level the formation level. The paradigm can be described in a matrix which allows some estimates of time and cost to be calculated using a spreadsheet. Chapter 7 uses the framework to develop a methodology for readiness evaluation based on critical path analysis with resource constraints[2]. Chapter 8 presents cost estimation methodology. A summary of the results and conclusions is given in Chapter 9. Two example problems are solved in Annex IV and Annex V.

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[1] Moore, Craig S., et. al., "Measuring Military Readiness and Sustainability", RAND R-3842-DAG, 1991.

[2] Critical Path Analysis is referred to as PERT (Project Evaluation and Review Technique) by some authors.

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CHAPTER 2

FINDINGS OF THE RAND CORPORATION

2.1 BACKGROUND

21. As part of the review of existing approaches, the ST conducted a survey of member nations and a literature survey of methodologies currently in use and proposed methodologies for readiness evaluation. Of particular note is RAND Report R-3842-DAG published in 1991 [Reference 20]. This document provides a comprehensive survey of readiness evaluation methodologies and systems that were in use in the US at the time. It identifies shortfalls in methodology, it proposes an interim solution to the shortfalls and it outlines requirements for an "ideal" methodology.

22. Since 1991, little has changed in terms of readiness evaluation methodologies, systems and requirements for better methodology. Therefore, the RAND report remains timely. Furthermore, while it specifically addresses the US situation, the observations in the report apply to other nations as well insofar as practices and systems in other nations are similar to those of the US. Because the report provided such useful background information to the ST, the main points will be summarised in this section as background information for the reader.

23. The RAND investigation was motivated by the need for defence decision makers to understand "the degree to which military posture can enforce national security objectives". The report noted that planners want to be able to relate the size, mix, and technology of forces, to operational objectives and endurance. Furthermore, it was noted that planners want to be able to assess how capability might change as the result of changes in policy and funding patterns.

24. The report revealed that in recent years R&S posture has been evaluated principally in terms of the resources that are available in individual operating units and in the estimated number of days of supply held in stockpiles of different materiel. The authors stressed that this information does little to answer important questions facing senior managers because it represents only the percentage of entitled allotments that are actually available. Because requirements and specialised preparations for operations change in response to operational scenarios, such information is

inadequate. Of itself, current levels of available resources and stockpiles can not be used to determine whether or not units and materiel would be available and ready when needed for an actual operations. Information provided through the SORTS system and S-rating system tabulations are extensive and detailed but they provide little insight into the mutual consistency of the status and availability of different types of units and materiel and hence the abilities of US forces to undertake and sustain operations of different types in different locations.

2.2 CHARACTERISTICS OF AN IDEAL METHODOLOGY

25. One of the main contributions of the RAND report to the work of the ST was a list of eight characteristics of an ideal R&S assessment method. In the view of the RAND authors, such a method should:

- reflect what units and forces can do, not just what they have;
- be practical (i.e. non-disruptive, inexpensive and understandable);
- be objective and verifiable;
- reveal the robustness of posture across scenarios with varying and somewhat unpredictable conditions within scenarios;
- provide useful feedback to the providers of elemental data;
- permit comparisons of status from one year to another;
- reflect the transition from peacetime to wartime;
- permit evaluation of trade-offs.

26. The ST accepted these "ideal" characteristics as valid goals to strive for. Chapter 9 will re-visit them against the R-C CPA methodology proposed by the ST.

2.3 IMPROVING CURRENT ASSESSMENT METHODS

27. DoD already has data, analysis and exercise/testing systems that address different aspects of R&S and the transition from peacetime to wartime. The report considered seven existing families of methods and proposed improvements for them.

28. Three of the families deal primarily with units:

asset reporting:

- compiling the quantities and condition of the equipment, supplies and people in individual units;
- here we recommend emphasis on estimating time required to reach specified performance standards and on maintaining only those resources necessary to train up to those standards i.e. we recommend training readiness;

unit modelling:

- simulation or direct calculation of the mission activity levels achievable with specified sets of resources;
- these could become more practical by streamlining their extensive data requirements;
- they could be made more useful by treating interdependencies between different units;

functional testing:

- measuring the abilities of individuals and units to perform (proxies of) their wartime tasks and operations
- testing should be carried out with shorter advance notice, more realistic (limited) equipping and preparatory training, increase the uncertainty about test content;

- instrumented means should be used to collect test results, and the results should be collected by disinterested evaluators.

29. The remaining four assessment families deal primarily with forces:

stockpile reporting:

- compiling the quantities and condition of the equipment, supplies and people outside of individual units;
- these compilations would be improved by accounting for more of the resources available by explicitly reporting the forces and operating assumptions that would draw down stockpiles and by emphasising the duration of different mission activity levels achievable;

mobilisation planning:

- determining the steps and schedules for assembling and organising military forces and for accelerating the production of military goods and services;
- improvement would accrue from identifying the times required to assemble different types of units and to train them to specified performance standards and then examining the integrity of the resulting forces that could be marshalled for deployment;
- need to provide greater depth in specifying wartime time-phased production and service capacities;

deployment/distribution planning:

- establishing the feasibility of specified force and materiel delivery objectives and determining corresponding movement, storage and materiel-handling schedules benefits would result from streamlining data and analysis tools and broadening the analysis scope, e.g. linking movement in the home nation, strategic movement to theatres and movement within theatres;
- recent studies have shown that deployment costs could be reduced by increasing readiness of deploying units; higher readiness would allow longer

transit times so that units at higher readiness could still get to combat zones on time but by slower means;

combat modelling and wargaming:

- these predict the results of force-on-force conflict in terms of measures such as territory gained or forces remaining;
- treatment of R&S limitations is embryonic in this area.

30. In general, these assessment families are disjoint and therefore the suggested improvements could be undertaken independently.

2.4 INTEGRATED ASSESSMENT FRAMEWORK

31. The report proposed to link all seven families using them as building blocks for a comprehensive integrated system aiming to achieve more of the ideal system characteristics proposed above. The authors cautioned that combat modelling and war gaming are too complex to include in the near term. However, they suggest that a system linking the other families seems practicable. Such a system would link information about:

- peacetime operating tempos and training levels (including reserves);
- forward deployments;
- pre-positioned stockpiles and other materiel stockpiles;
- information about capacities and resource constraints;
- timing for mobilisation and deployment;
- information about combat activity.

32. Ultimately the system could be used to predict levels of capability as a function of time in various locations. Figure 2.1, reproduced from Reference 20, shows a conceptual system which links existing assessment systems.

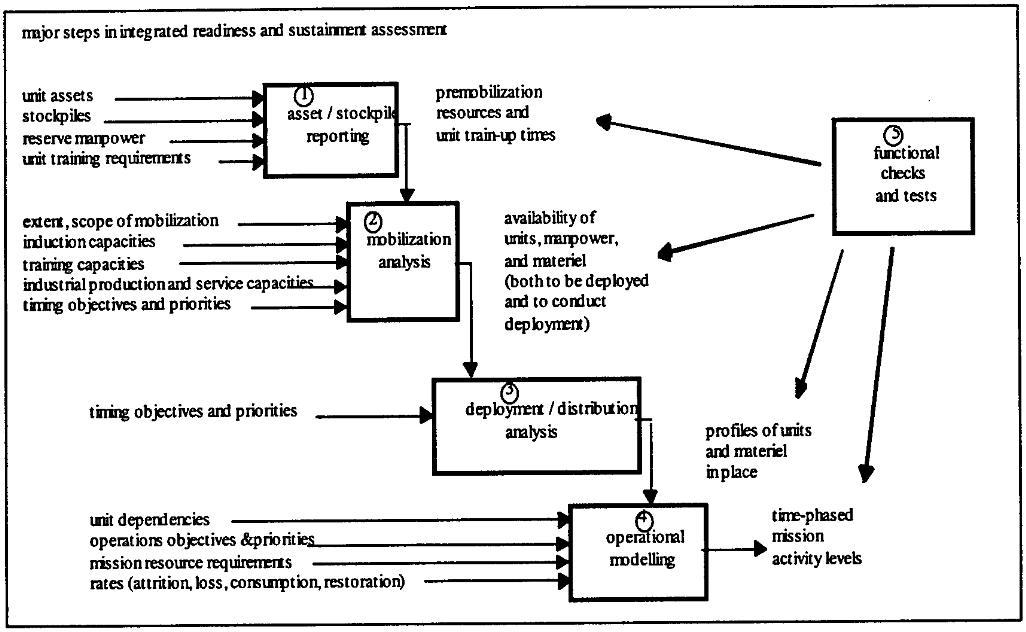

Figure 2.1: Overview of an integrated readiness and sustainment assessment system

33. The integrated system would allow mission activity levels to be tracked as a function of time. This activity level is directly related to the cumulative build-up of capability as a function of time. Figure 2.2, reproduced from Reference 20, illustrates the time Vs activity view of force generation.

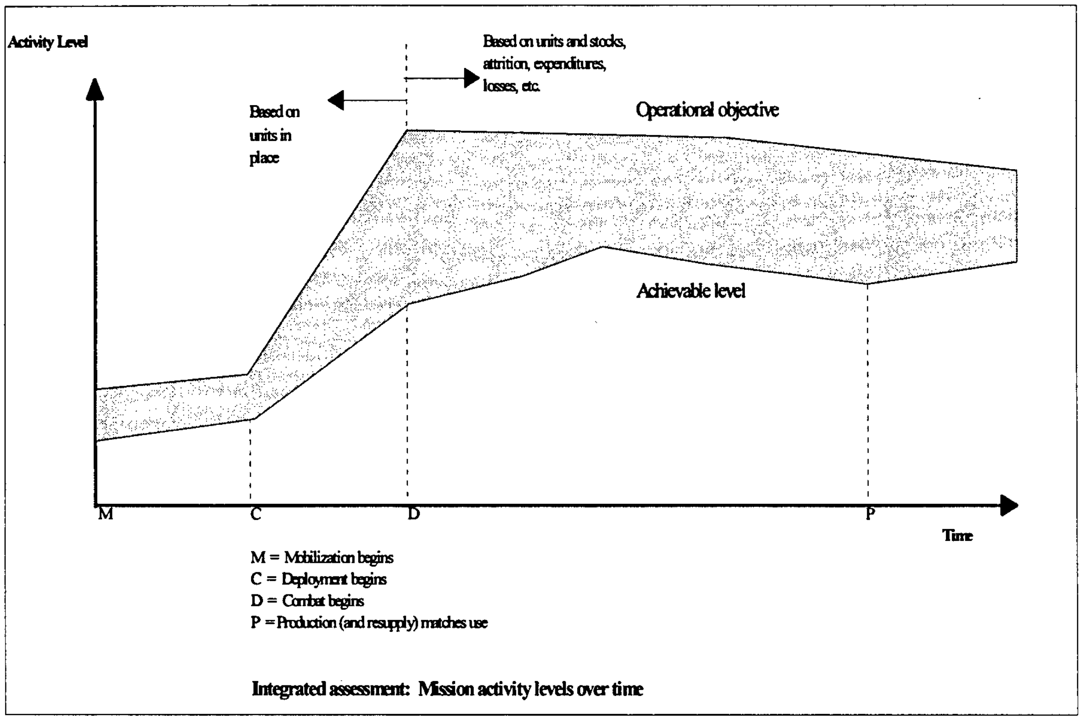

Figure 2.2 Activity levels as a function of time during force generation and force employment

34. An integrated assessment framework would function in the following way:

- asset and stockpile reports would collectively reflect the quantities of unit and non-unit personnel and materiel resources available, their location and condition;
- mobilisation analysis would project numbers of additional units, people and materiel that could become available over time and the changing levels of unit capability attainable (by means of additional training);
- deployment and distribution analysis would translate information about increasing unit and resource availability (also about increasing lift and handling capacities) into profiles of the increasing numbers of combat and support units and materiel that could be available at appropriate locations in combat theatres;

- operational modelling would use assumptions about quantitative mission / engagement objectives, (and corresponding expenditure, loss, attrition rates, and so on), to translate the profiles of available units / forces and materiel into profiles of the activity levels achievable over time for different mission areas;

- functional checks and tests would be used to the maximum practical degree to estimate - or at least verify - the input/output and time/capability relationships used in the other steps of the process.

35. The report recommends that R&S assessments should be easily understandable to high-level decision makers and should be comparable from year to year. Assessments should reveal any inconsistencies among force elements and resources and should identify bottlenecks (and corresponding structural or resource shortfalls) that restrict mission activity levels. The framework would permit estimation of the effects of eliminating such bottlenecks / shortfalls, allowing comparisons of these effects with corresponding cost estimates. Such assessments would provide information much more relevant to high-level decision makers' questions about consistency between the military's readiness and sustainability and the nation's security interests, objectives and commitments.

36. Because an integrated framework would take some time to develop (or might ultimately be infeasible) the report recommend that DoD undertake enhancements in R&S assessment in four categories: unit readiness, force readiness, sustainability and overall integration. Specific recommendations were as follows:

unit level readiness

- define performance measurement scales and standards for different types of units;
- develop systematic means for estimating how long units would take to achieve different levels on the defined scales;
- hold each unit responsible for reporting the resources it needs to maintain its peacetime proficiency and to accomplish its performance upgrades through pre-deployment training;

- develop and conduct functional tests and experiments to confirm or refute the training time estimates.

force readiness

- build on performance-based, time oriented representation of unit readiness
- co-ordinate databases of:
    - i. induction, individual training, individual and unit processing, and unit training capacities that would provide services and resources to units in contingencies;
    - ii. personnel, equipment and supplies available to fill out units' resources and training before deployment or employment; and
    - iii. desired schedules for using units within combat theatres (recognising the functional dependencies among units).
- project timing profiles of the number of units of different types that could be filled out, trained and prepared for deployment (if still in the home nation) or employment (if already in theatre).
- identify shortfalls from the desired deployment schedules perform such assessments for different scenarios - distinguished by scale, region, and warning / preparation, for example.
- obtain reviews and comments from theatre commanders.

sustainability

- use information about:
    - i. pre-positioned stockpiles,
    - ii. resources available in the US and the combat theatre (including industrial production), and
    - iii. allocations of movement and handling capacity,

to project the cumulative quantities of materiel and replacement personnel available in operational theatres;

- delineate assumptions and ranges of uncertainty for key rates, (e.g. weapon system attrition, materiel and personnel losses, and supply consumption) associated with different types of mission activity; use them to estimate the cumulative supply profiles, estimating as a function of time any corresponding shortfalls below mission-area activity level goals;

- investigate the sensitivity of the results to any assumptions that were made and perform assessments for different scenarios;

- obtain reviews from theatre commanders.

overall integration

- explore the feasibility of developing and operating the integrated framework in two ways:

    i. linking existing analytic methods and data;

    ii. designing and building an ideal system unconstrained by the detailed complexities of existing methods

- compare corresponding advantages and disadvantages and estimate the costs and risks ;

- if one approach or a combination of the two seems sufficiently promising, develop and test it experimentally;

- if the results warrant it, proceed with system development and regular application.

37. The recommendations made in the report are useful guidance for the development of the new systems for evaluating and reporting joint readiness. In Chapter 9, an assessment of the R-C CPA methodology will be made in terms of the "ideal" characteristics put forward at paragraph 24.

CHAPTER 3

NATIONAL LEVEL REQUIREMENTS FOR READINESS EVALUATION

3.1 READINESS EVALUATION

38. Readiness evaluation should provide nations with the means to determine the time required for a military force to reach a specified level of operational capability. Readiness evaluation methodology is needed to verify that prescribed readiness standards are practicable and to determine readiness standards that are achievable if resource levels change or if threat assessment indicates that more stringent standards are needed. Readiness requirements can be stated on the basis of each task or mission element for each unit in terms of operational capability objectives and response time. Depending on the type of operation, the tasks and mission elements, the required operational capabilities and response times must be derived for individual organisational elements (units), groups of collaborating elements (formations) and the organisation as a whole.

39. Nations should be able to relate the readiness levels of military organisations, formations and individual elements to operational capability and response time for missions and tasks. At each level, the appropriate readiness level should be mission or task dependent. However, the relationship between the readiness levels of an organisation, the readiness level of a formation and the readiness level of a unit is not always straightforward. These relationships need to be addressed by an appropriate readiness evaluation methodology.

40. Readiness evaluation methodology must be able to assess timing requirements and operational capability requirements at the unit level. Readiness reporting systems typically present an assessment of readiness in terms of indicators which rate personnel availability, training status, stockpile levels and equipment availability. In some systems these states are aggregated into a single quantity. This method of asset counting is not enough to *predict* readiness, especially not at the formation and organisation levels.

41. Readiness evaluation methodology should be able to aggregate relevant information from as low as the unit level in order to assess readiness requirements that have been defined above the unit level and to estimate their impact at the unit level.

This implies that methodology must be able to assess readiness of organisational elements from the unit level up to the formation level. To be able to evaluate readiness of formations, it is necessary to assess the consequences of units sharing resources and units synchronising activities during force build-up.

42. At the unit level, the readiness evaluation methodology must be general enough to be applied to any unit. This imposes a significant burden of data and algorithms on a readiness evaluation and reporting system. Ultimately, the lowest level of organisational unit that the system can assess might depend on the type of operation (e.g. peacekeeping vs. mobile counter concentration) or on the size of the organisation. The latter might determine the lowest level of formation outside, the standing organic structure, that would ever be deployed..

43. Readiness evaluation methodology should be able to distinguish from among many suitable units that are potentially "ready", in order to evaluate readiness for an operation. In other words, there might be several ways to build a formation for an operation. On the other hand, units may be totally unavailable because they are participating (or have been participating) in an ongoing operation.

44. Readiness evaluation methodology should be able to make appropriate and realistic assessments in cases were organizational elements have a steady-state which is significantly different from the requirement for a proposed operational role. It might be the case that the skills and mission elements that are emphasized in the steady-state activities are dramatically different from capability generation activities and operational activities. Consider a situation in which a combat unit is brought into a peace support or humanitarian aid operation because of some specialized mission element that is needed in the operation. In such a case, it might be that the skills needed for effective peace support or humanitarian assistance, both at the unit level and at the level of individual soldiers, are lacking. Thus, in such a case, a readiness evaluation methodology should be able to identify the shortfalls in appropriate training and skills and flag all tasks and mission elements that the combat unit should be excluded from unless sufficient response time exists to redress the shortfalls in training or doctrine.

3.2 READINESS POLICY EVALUATION

45. The evaluation of readiness policy should enable the economy of readiness to be balanced against sufficiency of capability and response time. Such trade-offs should be carefully assessed by competent methodology. Such methodology should be

able to evaluate the cost associated with the readiness of the organisation in steady-state and the cost associated with the surge processes of force generation so that economical trade-off between surge costs and steady state costs can be made.

46. Readiness policy addresses the choice and implementation of readiness standards. Policy must necessarily be evaluated. However, because readiness policy determines readiness practice, it follows that readiness evaluation methodology should be able to play an integral part in readiness policy evaluation, along with cost estimation and risk assessment. Thus, it should be possible to express changes in readiness policy in terms of input to the readiness evaluation methodology. So, for example, if the readiness evaluation methodology is resource and activity based, then it is necessary to be able to express all readiness policy changes in terms of changes in resources and activities.

47. At the level of policy evaluation, methodology should be able to address such issues as:

- moth-balling equipment,
- force mix (conscripts vs. volunteers, reserves vs. regular forces),
- closing or combining facilities,
- reducing stockpiles,
- reducing training, and
- reducing maintenance.

Methodology is needed to estimate savings in the recurring costs of armed forces that would result from such policy changes.

48. If the affects of policy changes can be assessed by the readiness evaluation methodology, conversely, it should be possible to use the readiness evaluation methodology to look for attractive policy changes. For example, it should be possible to identify stockpiles that could be reduced or training facilities that could be closed without affecting readiness.

49. The data required by readiness evaluation methodology and policy evaluation methodology should draw upon existing electronic data sources wherever possible. Data requirements should be kept to a minimum. Wherever possible, data should be factual, objective and easy to obtain.

50. Sustainability requirements impose readiness requirements on logistic support units. If the organisation is not ready to sustain a given operation for a projected period of time, then it could be argued that the organisation is not *ready* to perform the operation. However, the operation could be mounted while the surge of sustainment capacity is still in progress.

CHAPTER 4

NATO ALLIANCE LEVEL REQUIREMENTS FOR READINESS EVALUATION

4.1 INTRODUCTION

51. Readiness criteria for the forces of NATO nations are developed to support the mission of the two Major NATO Commanders (MNC). The Supreme Allied Commanders of Europe (SACEUR) and the Atlantic (SACLANT) each have a mission to defend the Alliance, and will support each other in the execution of their missions. To this end, defence plans are developed with prescribed readiness criteria to ensure the timely arrival of forces. The two MNCs develop force requirements for NATO nations specifying the need for the size and build-up of forces. Subsequently, in the NATO bi-annual force planning cycle, the MNCs develop, in close co-ordination with the nations, Force Proposals which are a realistic military assessment of the expected contributions of the MNCs from the nations. These proposals are submitted to the Military Committee (MC) and the Defence Planning Committee (DPC), who screen them, amend them and publish them, after mutual agreement with the nations. The resultant proposals are referred to as Force Goals. Force Goals are the official NATO plans for the alliance force structure.

52. Within the Force Proposals, the MNCs require certain readiness conditions for the forces assigned to them. During the Cold War the threat was well defined, consequently the appropriate readiness posture could be determined quickly. At present, however, with the introduction of the new NATO strategy, the appropriate readiness posture is not as clear. There is growing recognition that NATO is confronted with multi-directional and multi-faceted risks. A spectrum of contingencies might arise, each demanding a distinct response from NATO. Response options differ in the level of forces to be employed, the type of mission to be performed and the location to be considered.

53. The new NATO Force Structure, as defined in MC 317, has adopted the requirements for a flexible, mobile and multi-national force structure. Flexibility is required because of the uncertainty about which contingencies may arise. Mobility is required for quick re-distribution of forces as a crisis develops. Multi-national forces are required to ensure the cohesion of the NATO Alliance in its response to any

emerging crises. MC 317 divides forces into categories of Immediate Reaction Forces, Rapid Reaction Forces, Main Defence Forces and Augmentation Forces. For each of these categories, standard readiness criteria are assigned. However, these readiness criteria may not be sufficient to provide response in the required locations by the required date.

54. For example, a unit that can be ready within 5 days, but which requires 30 days to deploy because it is heavily equipped does not contribute to the deterrent and defensive posture for a contingency that requires a 14 day response interval. If similar evaluations for that particular unit against a spectrum of contingencies reveals that extra days for deployment are typically required, then the readiness criteria should be adjusted.

55. From a NATO perspective, readiness criteria should be established after assessing all of the likely contingencies to which a unit might contribute, and should be the result of back-plotting from the required response time. Under this approach, determining the readiness criteria for a unit becomes a matter of identifying all of the appropriate contingencies and calculating the required response times.

56. While the previous chapter has discussed readiness evaluation from a national perspective and has tried to develop criteria and requirements for methods to evaluate formation readiness from a national point of view, an equally rational and logical approach should be used to derive NATO required readiness levels. Ultimately, readiness criteria should be based on the effective employment of forces.

4.2 REQUIRED READINESS LEVELS

4.2.1 Unit Level Readiness

57. Recalling the definition taken from NATO document MC 55/3, "Readiness and Sustainability Factors", readiness of a unit is considered to be the time within which the unit can be made ready to perform unit type tasks and is amplified by indicators of its current personnel, material and training state. This preparation time is not to include transit time.

58. Thus, for NATO, unit level readiness is well-defined and unambiguous. In defining required readiness levels from a NATO Alliance perspective, factors such as movement times, preparation times etc. are being introduced. The definition of unit readiness is not being corrupted; actually, the unit level timing calculations still have to be considered, in order to present the nations with well-defined and clear readiness

criteria. Unit readiness levels are determined both by the nations, who assess the appropriate training and equipment requirements of their forces, and NATO, who must assess if for any proposed scenario and force package, the required deployment dates can be met.

4.2.2 Readiness for Higher Level Formations

59. Readiness criteria for the higher level formations are dependent upon the way in which the units in the formation are to be employed. Only if that level of detail is addressed can the required readiness levels be determined from an Alliance perspective. In cases where a formation or task force is being raised to perform a particular mission at a particular time and location the MC 55/3 definition does **not** apply to the readiness of the higher level formation. Again, the formation readiness depends upon the employment plan for the force in question. Transit times, work up and preparation times at the destination become factors in the calculation of formation readiness.

4.2.3 Calculation of Required Readiness Levels

60. Assuming a possible contingency in which NATO might decide to deploy forces, the calculation of required readiness for a formation would involve the following steps:

i. the task assigned to one of the MNCs involves first of all the selection of a suitable force package to include the units and the location of deployment.

ii. then for each of those units a required deployment date (RDD) would be determined along with a priority of arrival.

iii. once the RDD date has been established, backdating will establish the readiness required.

iv. the readiness of each unit is then determined by:

(a) work-up time at the home base/home port (if necessary);

(b) transit time from peacetime location to theatre destination considering 2 cases:

(1) self-deployment; and

(2) road/rail movement, staging, sealift and airlift;

(c) preparation time for the higher formation to be combat ready.

61. The work-up time for any unit may be case-dependent. This is because that while timings for most of the activities related to work-up may be included in the prescribed readiness of the unit (as per the definition of unit readiness), there might be specific cases that require a special work-up period; this would be the case if a particular contingency included irregular tasks which had originated as new requirements. For example, in a peace support operation a unit might be tasked to perform policing activities for which it has not been specifically trained. Thus, the term "unit type tasks" in the definition of unit readiness might include tasks which are unanticipated in the planning and time estimation process.

62. Transit times for self-deploying units can be calculated in a straight forward way. For example, the time required for a carrier battle group to reach a contingency area depends only the distance to be travelled and the average speed. Realistic surrogate values for distance and average speed adequate for planning purposes can be readily determined and consequently the expected transit time for a carrier battle group can be readily determined.

63. Transit times for non-self-deploying units require more sophisticated calculations. Their movement depends upon the availability of potentially scarce transportation resources to be available at the right time and at the right location. While rail and road movement is not regarded as problematic, although they require careful planning and will draw upon a considerable part of the civilian rail and road infrastructure, NATO estimates that the strategic level of the movement would be the most challenging. Civilian shipping and aircraft transport industries may not be able to provide the military movement with sufficient sea and airlift capability to satisfy the large surge demand that would be generated by the deployment. It is estimated that a division-sized movement would require at least 50 small ship sailings. If the contingency area is on the periphery of the NATO area or beyond and port congestion occurs, a deployment of one division might take as much as two months and a full corps might require three to four months to deploy.

64. Once units have arrived at their final destinations, a certain period must be taken into account during which time they would become fully mission ready. This period might include an interval for the units to become familiar with their new operating environment, to co-mingle with the other forces, and to establish communications, logistics and command and control.

4.2.4 Readiness as a timing problem

65. As defence budgets decrease, the readiness of units is sometimes decreased in order to reduce costs. Costs are the primary driver in setting peacetime readiness standards for military units. However, while this is true in peacetime, costs become of secondary importance after a nation has decided to employ armed forces in a contingency. While a nation might try to minimise costs for a deployment, the prime concern becomes timely deployment of sufficient military force to deter aggression and thereby subdue the crisis. From the Alliance point of view, timing and size of the response become the most important factors in the equation.

66. Thus, there is a trade-off to be made between national level efforts to reduce spending, (which tends to degrade readiness standards), and NATO alliance level requirements to ensure timely deployment of sufficient force, (which tends to elevate readiness standards). The bilateral agreements between NATO nations and NATO alliance level military authorities should address the minimum time required to employ forces, allowing nations the latitude to reduce readiness levels wherever acceptable from the point of view of NATO security.

4.3 SCENARIO CONSIDERATIONS

4.3.1 The spectrum of possible contingencies

67. The calculation to determine the readiness of a formation has been sketched in paragraph 58. For such a calculation to be implemented, it is necessary to make a number of assumptions on the deployment of forces in crises. When all the parameters are estimated, it is possible to calculate movement and deployment times, to assess preparation times, and to estimate readiness requirements.

68. A number of software tools are available to assist planners in the time estimation process. Computer simulations for deployments and a variety mathematical models, can yield an evaluation of required readiness time whenever scenario-based assumptions can be quantified. However, the diversity and variability of the assumptions makes the assessment difficult considering the number of possible deployment options for any particular unit and the number of formations each might be contained in. A “worst case”, “best case”, “expected case” approach could be used to guide planners in setting pragmatic readiness requirements for individual units.

4.3.2 Flexibility and Uncertainty

69. By introducing flexibility into force structure, strategy and so on, greater uncertainty is consequently introduced into predicting the effectiveness of deploying armed forces. This uncertainty is inherent in the prediction problem. Risk analysis allows potential consequences of increased flexibility to be assessed; principles of risk management can be applied to operations plans in order to obviate unacceptable outcomes.

CHAPTER 5

A READINESS PARADIGM

5.1 GENERIC FORCE GENERATION PROCESS

70. The process of force generation can be described by a generic paradigm:

- strategic assessment determines the size of the force to be raised, its composition, the expected duration of the conflict, the level of intensity, the theatre of operations and the required response time;
- from this follow the operational capabilities, tasks and mission elements that are required to be generated along with the numbers of units required and the resources that they will need to mount sufficient response to the threat;
- training requirements and other preparations that must be made at the level of individual units are determined;
- joint preparations and joint training requirements for groupings of units are identified;
- movement requirements for training and deployment of units into the theatre of operations is assessed.

71. Having identified capability requirements, and the types of units that can provide the capabilities, a matrix view of preparation and transportation activities can be generated. Figure 5.1 is a matrix view of the generic force generation process.

time

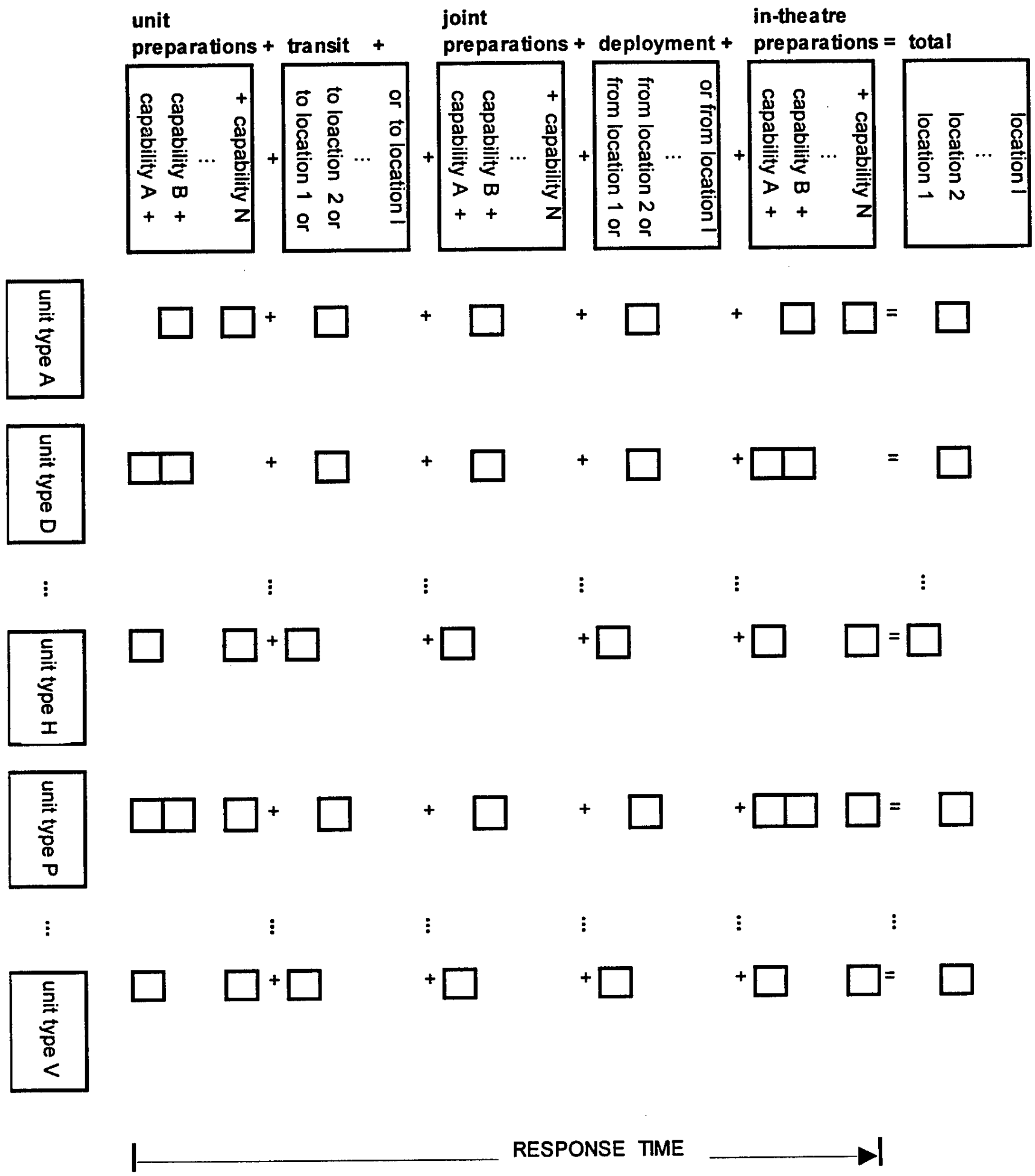

Figure 5.1: A Generic Force Generation Process

72. Figure 5.1 depicts a view of capability vs. time for a collection of unit *types* which are labelled *A, B, ..., V*. The units of each type make preparations at their home base, they are then transported to any one of a number of other locations for collective training. After collective training, they are deployed into the theatre of operations where they continue their preparations until such time as they are declared ready.

73. In Figure 5.1, preparations and training are classified according to capability components which are labelled *A, B,...,N*. There may be activities carried out at the unit level that contribute to more that one capability. For example, aircraft repair, which is done at the unit level, contributes to all of the capabilities of the Air Force. However, there may be re-configuration activities carried out by the maintenance section that contribute to only one specific capability. In such cases, activities that contribute to more than one capability can be attributed equally among them

74. As many unit types, as many capability components and as many training locations can be included in the template as required. Furthermore, Figure 5.1 depicts only three phases of preparations and training: unit level, collective training prior to deployment and collective training in theatre. As with capability components and training locations, as many training phases and transit phases as required can be included.

75. Templates such as in Figure 5.1 can be generated that record both time and cost for each activity. By summing over the units, an estimate for the total time and the total cost for each unit can be made. This estimate must be treated with caution, however.

76. Estimates obtained by summation of activity timing and cost may be rather coarse approximations. A careful estimate of the response time for any unit type is more complicated than merely summing the timings for its activities. There are a number of other considerations to be made:

- for any unit type, some training activities might be done in parallel rather than sequentially;

- conversely, there might be additional precedence relationships, not shown in the matrix, that will delay the start of some activities;

- constraints on resources might induce delays in the scheduling of activities; for example, if there are not enough transportation assets to execute the transit events as soon as a unit is ready to move, then some additional waiting time will be added.

77. A more detailed view of the generic problem is given in Figure 5.2. Here, timing or cost estimates for specific units of each required type are recorded.

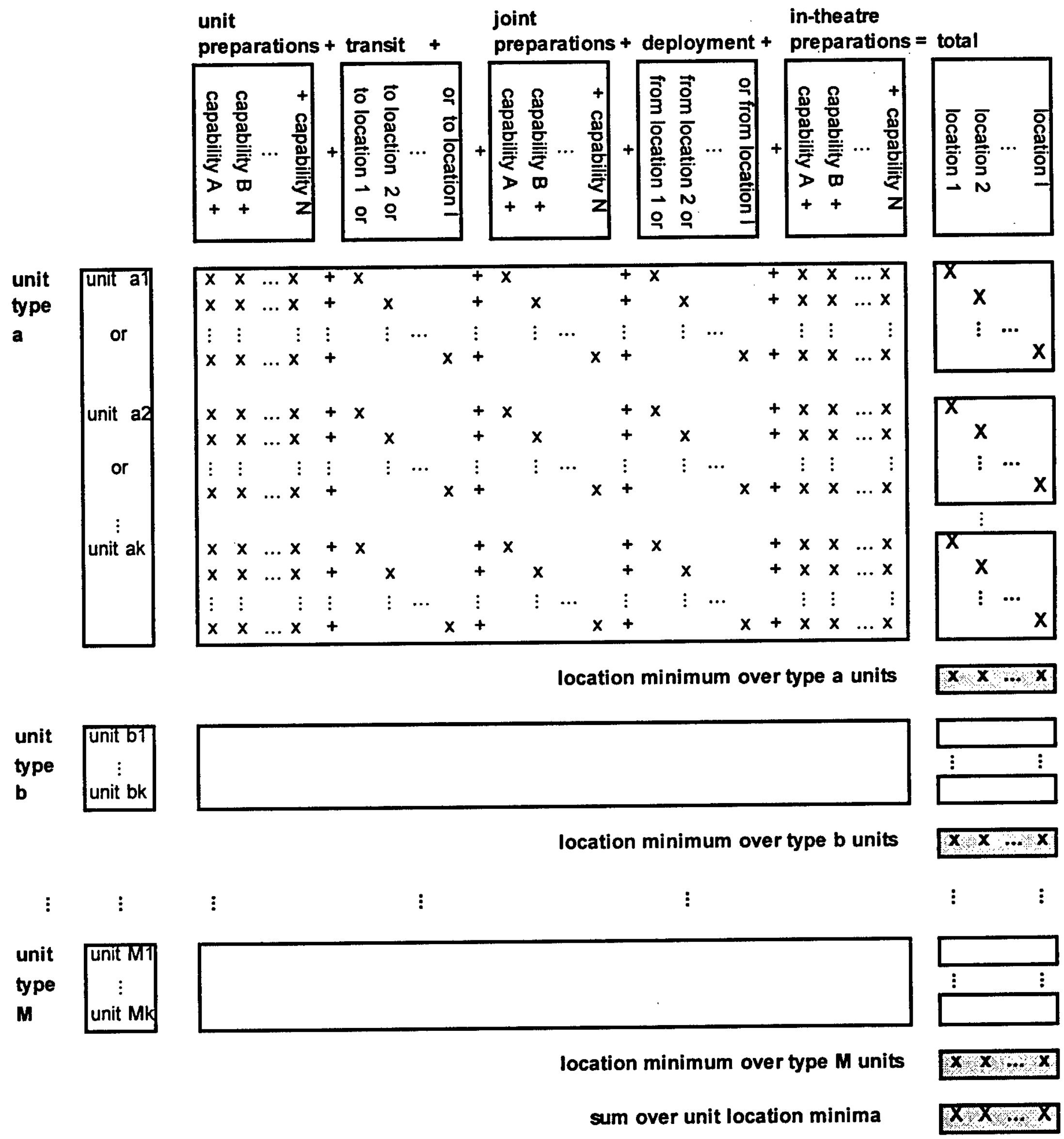

Figure 5.2: A More Detailed View of the Generic Force Generation Process

78. In Figure 5.2, each of the unit *types* that appear in Figure 5.1 is replaced by as many as k actual units of the appropriate type. Here, the actual units that populate the matrix represent viable options for participation in the operation.

79. Specific time or cost data for each of the units can be recorded in the matrix of Figure 5.2. This data is depicted by x's in the matrix of Figure 5.2. Then, a time estimate or a cost estimate can be made for each unit by summation.

80. There is an additional degree of flexibility that can be introduced into this estimation process. The location for joint training may be optional. Planners might want to consider the lowest cost location or the location that minimises the response time. Figure 5.2 includes labelling for up to l options for the location of joint training. An estimate for time or cost can be made for each unit performing its joint training at each of the optional locations.

81. The total time or the total cost for each unit at each training location appears on the far right of the matrix in Figure 5.2. For each location, selecting the lowest cost option for each of the unit types and then summing the selections over all of the unit types yields an estimate for the lowest cost force that can be mounted using that particular training location.

82. In a similar manner for time, the shortest response time for each training location can be estimated. The lowest cost force that can be mounted is estimated by selecting the training location with the lowest total cost. Similarly, the force with the shortest response time is estimated from the joint training location with the lowest response time.

83. Recall, however, the remark made in paragraph 73, that estimates based on summation might be somewhat coarse, and the considerations listed in paragraph 74 which outline the need for a more careful approach to determine the actual cost or the actual response time. It is necessary to call into question the accuracy of the estimates made for training locations when attempting to identify the training location with the lowest actual cost or the shortest actual response time.

84. In order to identify the lowest cost force option or the force option with the shortest response time, estimates were *compared* for each of the locations. Thus, because the selection is based on *relative size*, the coarseness of the estimates is of secondary importance. Provided that the relative size of the estimates correlates reasonably well with the relative size of the actual values, then the selection approach is valid.

85. Thus, for each of the summation estimates, the precedence relationships, resource levels and infrastructure are necessarily the same. In other words, all of the significant factors that cause the actual response time to differ from the summation estimate, are held constant across the estimates. Therefore, it is reasonable to expect that the summation estimates are approximately proportional to the actual values. As a consequence, relative comparisons of summation estimates are valid and hence, the selection of minimum response time forces and minimum cost forces based on summation estimates is not unreasonable.

CHAPTER 6

FRAMEWORK FOR READINESS EVALUATION

6.1 UNIT LEVEL READINESS

86. Readiness of a military unit is time, according to the NATO definition:

"readiness of a unit is considered to be the *time* within which a unit can be made ready to perform unit type tasks and is amplified by indicators of its current personnel, materiel, and training state. This time does not include any transit time."

87. To put a practicable scope on quantitative analysis, assume that readiness requirements are given. That is to say, assume that a set of "benchmarks" for standards that a unit must meet in order to be designated as "ready" to perform any of its assigned tasks are given. This does not preclude the possibility that some or all of the "benchmarks" were previously determined by means of other operational analysis.

88. The NATO definition implies that readiness can be evaluated as a function of the unit formation, the infrastructure supporting it and the benchmarks associated with the tasks:

$$readiness(unit, infrastructure, benchmarks(task)) = time$$

$$\begin{aligned} attributes(unit, infrastructure, task) = \; & state(personnel), \\ & state(training), \\ & state(materiel), \\ & state(equipment) \\ & state(command\&control) \end{aligned}$$

89. The list of attributes given in the above conceptual equation is not necessarily complete. There may be other attributes that might be considered depending upon the circumstances. Here, "state" is intended to be a measurable function of the associated evaluation areas. Note that the "benchmarks" might include target values for any or all of the "states" of the attributes. In this manner, readiness can be directly linked

to any attribute. For example, readiness can be linked to "availability of equipment" or "training" or whatever attributes are considered to be critical.

90. In other words, readiness can be derived as a function of any or all of the attributes plus other benchmarks. We require that the benchmarks be given in quantitative terms in a way that the time to achieve them can be determined by critical path analysis or some other quantitative method. It suffices to describe each benchmark using a set of activities which must be accomplished in order to achieve it. The activities must be described in terms of estimated duration, resource requirements and precedence relations.

91. It is worth noting at this point, that for a given unit, infrastructure and task, the actual data required to evaluate the conceptual readiness function might be quite considerable. Furthermore, the benchmarks, in some actual cases, might involve a certain amount of subjective judgement that might somehow have to be quantified. Moral, for example, is often factored into the evaluation of readiness and is often based on the Commanding Officer's subjective evaluation of moral. In cases where hypothetical readiness scenarios are being assessed as part of a parametric study, indirect indicators of moral, such as frequency of sick leave, might be used as a surrogate for the Commander's assessment.

92. To summarise the discussion thus far, a framework has been derived for quantitative analysis of readiness based on the NATO definition of unit readiness. The definition is given in terms of "units" and "unit type tasks". However, the Specialist Team has been tasked to address flexible readiness and joint readiness and therefore, the framework must address formations composed of multiple units and military objectives composed of multiple tasks.

6.1 FORMATION LEVEL READINESS

93. The notion of readiness as a function of formation, infrastructure and benchmarks can accommodate formations larger than single units and military objectives which are the outcome of the successful completion of many tasks.

94. Assume, that a military objective is given which consists of a set of tasks that will be assigned to a formation which consists of a set of units. Assume, furthermore, that a set of "benchmarks" is given which the formation must meet, as a whole, in order to be rated as "ready" to undertake the objective. Some of the

benchmarks may involve single units only, while others may involve joint preparations, e.g. joint training.

95. Target values for the benchmarks might be arrived at by operational analysis or they might be given based upon military judgement and experience. However, they must be given in quantitative terms in such a way that a quantitative method such as Critical Path Analysis (CPA) can be used to determine the length of time required to achieve them. Again, the "benchmarks" might include target values for any or all of the "attributes" under consideration thereby allowing a direct link between attributes and readiness. Thus:

readiness(formation,infrastructure,benchmarks(objective)) = time

attributes(formation,infrastructure,objective) =
state(personnel),
state(training),
state(materiel),
state(equipment)
state(command&control)

96. The problem of evaluating readiness then becomes a problem of deriving timings to achieve individual benchmarks, identifying resource constraints and establishing precedence relationships among the constituent activities so that Resource-Constrained Critical Path Analysis (CPA) can be used to determine the time required for the formation as a whole to achieve all of the benchmarks.

97. While the NATO definition of readiness specifically excludes transit time from readiness, it is nevertheless valid for military planners to consider the overall timing requirements such things as readiness for combat operations in a deployed location. In this case, the framework can be used to evaluate readiness for a formation composed of a transport unit and a combat unit by using combat readiness at the deployed location as the military objective. In such a case, transit times can be explicitly included in the evaluation of readiness.

6.3 A REFINED DEFINITION FOR READINESS

98. The discussion of formation level readiness using the framework suggests a refined definition for readiness that is consistent with existing NATO

terminology and which can serve the purposes of quantitative analysis. There are two observations to be made in this regard:

- by focusing on time, the framework allows concepts of unit level readiness to be generalised to the level of formations;
- the framework allows concepts of operational capability to be linked to the dimension of time by means of the benchmarks.

99. By relating time to benchmarks and attributes, a refined definition of readiness can be given which generalises the unit level definition and includes the definition of operational readiness:

Given a set of units, and for each unit, a set of target values for benchmarks of personnel, training, logistic support, equipment and command & control. Then:

readiness is defined as the time required to perform a set of activities that brings the benchmarks to the target values for each unit.

100. Consider that joint readiness can be addressed by this definition. For joint readiness, the units are simply those units which make up the proposed joint force; the activities will be taken as the proposed force generation activities for the operation; the benchmarks and their target values are chosen appropriately according to measures of effectiveness for the proposed joint operation.

101. Furthermore, flexible readiness can be addressed by this definition. Note that the definition places no specifications on the "activities" other than the requirement that they raise the benchmark values to the given target values. As well, no specifications are given for the initial values of the benchmarks. Thus, there is considerable flexibility for the activities and the units that are brought into the readiness evaluation framework. As long as some timing relationship exits between the activities and the benchmarks for the given set of units then readiness of the units can be evaluated.

6.4 RISK ANALYSIS

102. Risk is typically associated with readiness. This is because the predictions and assumptions that must necessarily be made in order to estimate adequate response time are subject to uncertainty and, therefore, there is always some risk that the

assessed readiness posture might be insufficient for the successful accomplishment of military objectives.

103. As well as risk from the point of view of sufficient response time, there is also risk from the point of view of sufficient resources. Employment of military capability necessarily requires resources. The level of each resource required at the outset of an operation and the timing and rate of re-supply of each resource during the operation must be estimated. In order to estimate the total resource requirements during any time period after the force generation process begins, the scale, intensity and duration of an operation must be estimated. Again, as with time estimation, resource estimation is subject to uncertainty.

104. The framework allows risk analysis to be included in the evaluation of readiness. From the point of view of timing, critical path analysis enables probability considerations to be incorporated into the analysis of timings and thus the algorithmic considerations made so far are, suitable for incorporating the time risk analysis as a by-product.

105. Supplementary statistical analysis and sensitivity analysis can be used to assess the risk associated with resource levels and rates of re-supply. Re-supply activities can be included in the activity description of the operation so that resource levels can be tracked as a function of time together with supporting estimates of the likelihood of resource deficiencies.

CHAPTER 7

READINESS ESTIMATION METHODOLOGY

7.1 BACKGROUND

106. Recall the NATO definition of readiness, that *readiness is time*. Therefore, it is necessary that a readiness evaluation methodology deal competently with time estimation. Furthermore, a number of independent studies have found that, to be useful to military planners, readiness evaluation methodology must competently *predict* timing requirements. The prediction must give a good estimate of the time required to "get ready" based on the "what" that the "readiness" is being generated "for".

107. The Specialist Team aimed at devising methodology to achieve these goals. The framework described in the previous chapter enables the problem to be viewed from a broad perspective so that maximum potential utility of methodology can result. Furthermore, by linking readiness to activities, achievement benchmarks, performance measures and, consequently, performance standards can be linked directly to activities and time.

108. Military commanders must cyclically assess the proficiency of their forces to accomplish the capabilities assigned to them, even during periods of low conflict potential. Capability necessarily varies over time insofar as it depends upon the availability and proficiency of people, the quality of training, the condition and suitability of equipment and other resources that vary over time. In the military context, the concept of "readiness" implies that, for whatever reason, the competence of a military force to perform its assigned tasks and mission elements should be assessed. This implies that in order to make a force "ready", it must undergo a *process* which will *assess* its *capabilities* and, possibly, *augment* or upgrade them as well. Therefore, the notion of readiness is intimately linked to the notion of *capability*, the notion of *process* and the notion of *assessment*; furthermore, processes require *time* to complete.

109. To bring readiness into question is to infer that a process has been prescribed or can be created in a timely manner for carrying out the required assessments and capability generation. It is typically the case that to reach operational task standards, some capability generation will be required. The economics of maintaining military

capability dictate that steady-state levels of proficiency, equipment condition, stockpiles and so on, be lower than operational levels. This is certainly true of training, which is almost always required before the commencement of operations. Such is usually the case for joint readiness. Assessment of capabilities implies that appropriate *performance indicators* and *performance measures* have been identified. Indicators must be correlated with actual results of realistic exercises and lessons learned from conducting operations. Hypothesis testing should be applied to determine the true utility of performance indicators and measures in predicting capability.

7.2 PERFORMANCE MEASUREMENT AND READINESS

110. Defence departments in many nations are moving toward implementing principles of Business Planning in order to glean greater efficiency from defence spending. From the Business Planning perspective, the concept of continuous improvement is the basis upon which performance is brought to high standards by means of processes that are themselves continuously improved. The idea is to use performance monitoring to determine cause and effect relationships between inputs, processes and outputs. The goal is to refine processes and minimise resources required to produce the requisite quantity and quality of the outputs.

111. The nature and number of performance measures required to build a sufficiently accurate picture of the actual performance of military organisations, for purposes of operations planning, is the subject of much study. For readiness evaluation, specialised indicators and measures have been proposed. A report from the General Accounting Office of the United States describes the results of a survey of "readiness indicators" used by military units in the United States.

7.3 MEASURING CAPABILITY GENERATION AGAINST TIME

112. It is a complex matter to establish reliable quantitative relationships between inputs, performance measures, performance standards, outputs and time. Currently much work is being done to put performance measurement on solid statistical and quantitative ground so that good estimates for the time required to meet performance standards and benchmarks can be made based on rigorous statistical studies of activities.

113. Quantification of relationships between performance measures and capability proficiency is a subject of considerable interest in such fields as Cognition,

Human Factors, Engineering, Economics, and Operational Research. The research falls into a number of categories:

- research aimed at building a general theory of learning, both at the individual and the collective level; Studies of human cognition;
- research aimed at a general model of the interaction between humans and machines, how should machines be designed to maximise their utility and ease-of-use;
- research that focuses directly on training, both at the individual and the collective level; references about training readiness;
- research into the relationship between training on simulators and training with real equipment;
- research that attempts to maximise the information gleaned from actual operations so that "lessons learned" can be used as the basis for making correct predictions about requirements for future operations.

114. In the absence of rigorous statistical results, military planners must nevertheless estimate timing requirements to achieve benchmarks for operational task standards. Typically, timing for unit level surge activities can be adequately predicted based on previous experience and military judgement. Thus, readiness evaluation for unit level tasks and mission elements is fairly straightforward because the scope and complexity of the evaluation problem is within the knowledge base of unit level commanders. However, the problem of readiness evaluation becomes progressively more difficult as the scope and scale of readiness preparations increase.

115. This chapter will develop the modelling approach and methodology proposed by the specialist team to evaluate the time dimension of readiness. The recommendation is to use Resource-Constrained Critical Path Analysis as the basis for readiness evaluation methodology.

116. Military capabilities result from the proper synchronisation and co-ordination of tasks and mission elements of military units; in general, tasks and mission elements can be described by activities that have resource requirements, precedence relationships and performance standards.

117. Readiness assessment in the context of force generation implies a process which includes augmenting capabilities. Therefore, there are two capability

levels in question: (1) the capability level at the outset and (2) the capability level after the process is complete; the process itself is very much a part of the question. The concept of creating the process (designing the process) in a timely manner is interesting insofar as it puts further scope on the notion of flexible readiness. (The trend toward "composite" operations planning could benefit from this level of flexibility.)

118. Processes consume resources; so readiness generation involves resources that are directly related to the capabilities they effect but also resources that are used by the process itself (*e.g.* some training will use ammunition over and above that which is the prescribed allotment for actual combat).

119. In order to provide sufficient background to a broad spectrum of potential users, both military and technical, notions about activity networks, linear programming, labelling algorithms, computational complexity and other mathematical concepts will be included. Furthermore, in order to achieve a unified and fluent development of the methodology, these concepts are included in the body of this chapter rather than relegating them to an annex.

120. Discussions with some potential military users of the methodology indicate a certain uneasiness on their part with the idea of analysing military operations using "project scheduling". In rebuttal, there are a number of points to be clarified.

121. Military commanders must use time and resources to generate and employ military capability in order to achieve military objectives; R-C CPA provides a very broad framework and a very powerful analytical tool to evaluate timing and resource requirements of a very general nature.

122. While there may be aspects of military operations that cannot be appropriately addressed with R-C CPA; there may, however, be aspects for which the opposite is true and it is worthwhile to investigate the potential utility of R-C CPA.

123. If R-C CPA alone is not sufficient to fulfil the analytical requirements of an application, it may be that in some cases R-C CPA augmented by other techniques will suffice.

124. Much of the jargon and presentation of "project scheduling" is tied to the culture and mentality of private sector manufacturing since historically, that is what it has mainly been used for and that is largely where software to implement "project management" is largely marketed; a re-think of the concepts and methodology addressing

potential military applications might assuage concerns about the utility of R-C CPA for military planning.

125. A number of case studies have shown that valuable information about military operations and readiness can be obtained using R-C CPA.

Network Representation of Capability Surge

126. Complex projects involving activities, timings and precedence relationships can be represented as a network consisting of nodes to represent activities and arcs to represent precedence relationships. The expected duration of each activity can be recorded using a labelling of the nodes of the network. The capability surge phase of military readiness can be viewed as a "project" and can, therefore, be modelled as an activity/precedence network. Consider the following example of a capability surge process for a military unit.

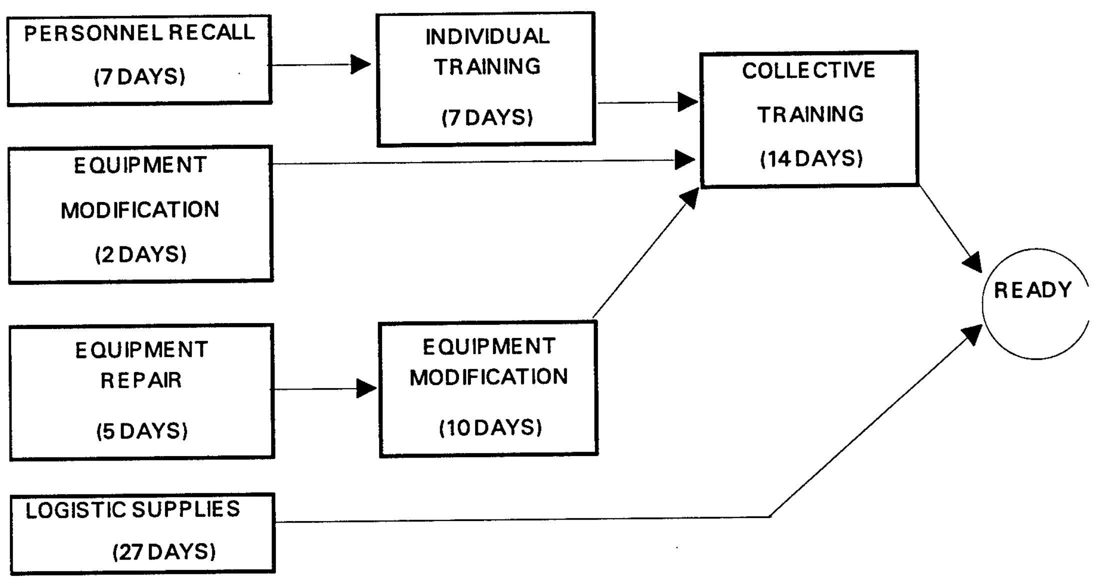

Figure 7.1: Network representation of Capability Surge

127. An inspection of the activity network in Figure 7.1 reveals that the earliest possible completion time for all of the activities, subject to the precedence relationships, is 29 days. The solution is fairly straightforward since there are only 4 paths from the beginning of the network to the end. By working forward along each path, the earliest termination time for the activities can be calculated. By observing that the earliest start time for any activity is the latest termination time for all of its immediate predecessors, it follows that the ready mark can be reached in 29 days.

7.4 THE CRITICAL PATH METHOD

128. The observation that "the earliest start time for any activity is the latest termination time for all of its immediate predecessors", forms the basis of an *algorithm* for solving the problem of finding the earliest completion time for an activity/precedence network. In the theory of scheduling, this problem is known as the *Minimum Makespan Problem* (MMP).

A Conceptual Algorithm for Activity/Precedence Scheduling

129. It is instructive to formulate a conceptual algorithm for MMP, as further background information for readiness evaluation methodology. Those already familiar with the critical path method and those not concerned about the details of implementing methodology might wish to skip to the next section.

130. The "algorithm" discussed in this section, is intended merely as an intellectual exercise to provide insight into the readiness evaluation methodology based on critical path analysis. The network is conceptualised with named labels on the nodes recording information about the activities that the nodes represent.

131. Assume an activity/precedence network in which each activity has a label stating its name, (label name *ident*), a label stating its start time (label name *start*), a label stating its end time (label name *end*), a label stating its duration (label name *duration*) and a label stating its status in the scheduling process (label name *status,* which will have its value set as either *scheduled* or *unscheduled*). Initially, *start* and *end* will be set to 0 for all activities; upon completion of the algorithm, *start* and *end* for each activity are set to values that achieve the minimum makespan for the network. In the following pseudo-code, *FLAG* is a variable which holds the name of the activity which is

being scheduled, *list* is a varying set of numbers, and MAX{*list*} is the largest value in *list*; adopt the convention that if *list* in empty, MAX{*list*} = 0.

Algorithm MMP:

Step 1. set *start = 0, end* = 0 for all activities;

Step 2. set the value of *status* for all activities to *unscheduled*;

Step 3. if all activities are labelled *scheduled* go to Step 7;

Step 4. select an activity that has no immediate predecessors with *status = unscheduled* and set *FLAG = ident* for the selected activity;

Step 5. for the activity with *FLAG= ident*:

set *list* = { *end*, for all immediate predecessors of *FLAG*};

set *start* = MAX{ *list* };

set *end* = *start* + *duration*;

set *status* = *scheduled*;

Step 6. go to Step 4;

Step 7. set *list* = { *end*, for all activities};

Step 8. minimum makespan = MAX{ *list* }.

132. The loop generated by Steps 4,5 and 6, does the work of scheduling the activities, starting with those activities that have no predecessors and working toward those activities that have no successors. Step 5 implements the observation that, "the earliest start time for any activity is the latest termination time for all of its immediate predecessors". If the network contains *n* activities, then, in less than *n* cycles through the loop, all of the activities will be scheduled.

133. In order to streamline the pseudo-code, Step 4 of the MMP algorithm has been stated rather tersely. In fact, Step 4 is a search procedure that should be programmed as loop in which, for the *unscheduled* activities, checking is done activity-by-activity on the status labels of immediate predecessors until a suitable *unscheduled* activity is found. Overall, Step 4 would involve about $\frac{1}{2}n^2$ passes through the search loop.

134. Thus, the amount of time needed to perform algorithm MMP is proportional to $\frac{1}{2}n^3$. This is the same order of magnitude as the time required to solve a system of linear equations. Therefore, one can expect to be able to solve MMP problems made up of thousands of activities and precedence relationships. In practice, this has been found to be true. Commercially available project scheduling packages **do** handle MMP problems involving literally thousands of activities and thousands of precedence relationships.

Slack Time

135. Having found the minimum makespan using the MMP algorithm, the earliest completion for each activity is known. By working backward from the end nodes of the network using a labelling procedure like the MM algorithm, the latest completion time of each activity can be determined such that the minimum makespan does not change. The difference between the earliest completion time and the latest completion time for an activity is referred to as the *slack* of that activity. Activities for which the slack is zero are referred to as *critical.* They are critical because if the duration is increased for any one of them, or if any one of them is delayed, then the minimum makespan will increase.

136. The minimum makespan problem for a critical path network (without resource constraints) is solvable in polynomial time. This problem can be represented as an LP and solved or it can be represented as an activity network and a "labelling algorithm" can be applied to the activity network.

137. In the following, Figure 7.2, the problem MMLP is an LP formulation of the minimum makespan problem.

Given:
tasks $A_1, A_2, \ldots, A_n$
with durations $D_1, D_2, \ldots, D_n$ *respectively*
and precedence relations $A_i \rightarrow A_j \; \forall \, (i,j) \in P$.

Let:
x_i *be the earliest start time for* $A_i, i = 1,2,\ldots,n$; *and*
y_i *be the earliest completion time for* $A_i, i = 1,2,\ldots,n$.

Define MMLP:

$$\min \, (y_n - x_1)$$

subject to:

$$\begin{aligned} & y_i \geq x_i + D_i, \;\; i = 1,2,\ldots,n \\ & y_j \geq x_i, \;\; \forall \, (i,j) \in P \\ & x_i \geq 0, \quad i = 1,2,\ldots,n. \end{aligned}$$

Figure 7.2: The Minimum Makespan Problem formulated as an LP

Resource Constraints

138. The problem MMP assumes that unlimited resources are available to perform the activities; for most applications this assumption is not valid. Here, the term "resource" refers to any non-consumable item or entity that is required to perform an activity. Resources can be such things as personnel, equipment, facilities and infrastructure. Resources can be classified according to whatever level of detail is needed to describe adequately the surge process which is being evaluated. For example, suppose that a surge process makes use of five CC130H transport aircraft and twelve CC130B transport aircraft, where the CC130H and the CC130B are two variants of the CC130 transport aircraft. For some applications it might be adequate to consider CC130

transport aircraft as one resource with seventeen units, while for others it may be necessary to distinguish between the CC130H and the CC130B as distinct resources.

139. The resource-constrained problem is described by activities, durations, precedence relationships, resources and resource limits. Thus, in addition to the activities, precedence relationships and activity durations of MMP, the required number of units of each resource is given for each activity together with the limiting number of units of each resource. Assume that activities cannot be interrupted once they are started and that, at any given time in the schedule, the total number of units of each resource in use must be less than or equal to the limiting number of units for that resource. The problem is to find a schedule that satisfies all of the precedence constraints and all of the resource constraints and has the earliest completion time. This will be referred to as the Resource-Constrained Minimum Makespan Problem (R-C MMP).

140. For example, suppose that for the example depicted in Figure 7.1, the facility that performs the activity *EQUIPMENT REPAIR* is the same as the facility that performs the activity *EQUIPMENT MODIFICATION* and that both activities cannot take place simultaneously due to a limitation in the capacity of the facility. Then, 2 additional days of elapsed time are required to complete both *EQUIPMENT REPAIR* and *EQUIPMENT MODIFICATION*. Hence, the minimum makespan is 31 days, with this resource constraint.

141. Resource constraints introduce a much higher degree of complexity into the problem. It is known that the scheduling with resource constraints and precedence relationships is in the class of mathematical problems known as NP-hard. Thus, R-C MMP is intrinsically difficult to solve.

142. The resource-constrained precedence scheduling problem requires a branch and bound algorithm to be solved. “Branch-and-bound” is a structured search technique for finding the optimal solution of NP-hard problems such as RC-CPA. The idea is to construct a tree of tractable sub-problems each of which is a relaxation of the overarching “hard” problem. By aggregating information derived by solving judiciously selected sub-problems a solution for the overarching will be found or it will be shown that no solution exists.

143. The survey paper at Reference 3 outlines the difficulties of solving R-C MMP. The network formulation of the problem appears to hold more promise than the LP formulation since the representation of the problem as an LP to include resource constraints is relatively large and requires integer variables. It is

apparent that LP-based branch-and-bound methods for this problem are not as efficient as network-based methods. If resource constraints are introduced, the LP formulation of the makespan problem becomes unwieldy to represent and computationally intractable even for even relatively small problems. For the resource constrained problem, a network labelling algorithm is essential in order to practicably implement the overarching branch and bound algorithm.

144. In many cases, however, branch and bound is not needed. For some problems, adjustments of start time for jobs with slack time will suffice to satisfy resource constraints. For other problems, activities tend to use only one resource and thus, for each resource, a scheduling sub-problem can be formulated involving only that one resource. Having solved each of the sub-problems, a master schedule can be constructed. In some cases, other planning considerations impose enough additional precedence relationships on the problem that the resource issue is resolved.

145. Feasible solutions are easy to find merely by arbitrarily delaying some of the activities until required resources are free. As a consequence of this, heuristics are easy to devise for the resource-constrained problem. Thus, if complete optimisation is impractical, good feasible solutions can be found by using heuristics.

146. If it is known that a resource is sufficient to accomplish all of the tasks that could be assigned to it simultaneously, then it is not necessary to include it in the resource constraints, since for purposes of the application at hand, it is effectively unconstrained.

147. The proposal to use CPA for evaluating the response time provides the machinery to "solve" the problem. If, however, the problem is too large to be solved, in a practical amount of time, then by aggregating tasks into summary tasks with less detail, CPA can be used to estimate the optimal solution of the detailed problem.

148. The issue of level of detail is a concern. How much detail in activities should be modelled to ensure that sufficient accuracy in the time estimates can be ensured. There are two main issues:

- timing estimates of individual activities; and
- the speed at which activities can be initiated so that co-ordination and synchronisation of activities can be achieved.

149. Regarding the first issue, data gathering can provide a solid basis for statistical estimates of activity durations together with estimates for the variance of expected timings. The variance of the estimate for the minimum makespan can be estimated by the largest sum of variances of activities taken over each path critical from the start to the end of the network.

150. Regarding the second issue, it is well known that the information required to trigger the initiation of activities is often not disseminated in a timely manner either through oversight, lethargy or error. This is a significant factor in the effectiveness of C^2 and C^2 systems in operations, [c.f. Reference 28]. The activity/precedence network can be used to identify information flow requirements to effect timely sequencing and co-ordination of activities. Information flow requirements can be explicitly included in the activity/precedence network as activities so that lag time in triggering activity initiation can be minimised.

7.5 SOFTWARE FOR THE RESOURCE-CONSTRAINED CRITICAL PATH METHOD

7.5.1 Background

151. The ST chairman undertook a survey of commercially available software to support R-C CPA. The survey paper at Reference 30 was very useful. Two of the products listed in the reference were tested: Microsoft Project® and SYMANTEC◆ TIMELINE®. After coding and experimenting with a number of test problems, it became evident that TIMELINE® (Version 6.1 for Windows) was capable of supporting the methodology for proof-of-concept purposes. Particularly noteworthy was its ability to optimise time in the presence of complex resource sequencing problems. Microsoft Project was less successful in this regard.

7.5.2 Useful Features of SYMANTEC◆ TIMELINE®

152. The program allows a hierarchical structure of activities by level of detail, starting from "project" at the highest level down to "detail task" at the lowest level through two other levels of aggregation; thus, the readiness preparations for a particular Air Force Squadron could be given as a "project" with "training" as a sub-

project, "air-to-ground flight training " as a "summary task" and "air-to-ground targeting training" as a detail task.

153. Resources can be assigned across multiple projects and, at any given time, a resource can be split among many projects.

154. Within defined periods of time, a resource can be assigned to one project exclusively while at other times it can be shared among several projects.

155. Precedence relations between detail tasks in separate projects can be established.

156. Named resources can be designated as interchangeable with other resources of the same type for specific tasks or they can be designated as essential for specific tasks. The software allows resource costs to vary over time and resource limits to vary over time.

157. Because TIMELINE® tracks time and resource utilisation, cost tracking follows naturally as a useful by-product. Special-purpose tables and graphs allow costs of tasks at all levels of aggregation to be tabulated and displayed. All cost information can be displayed in tabular form. Furthermore, cost per time period or cumulative cost over any interval can be displayed graphically as a function of time.

158. TIMELINE® is an ODBC-Compliant SQL which enables importing and exporting of data from other ODBC-Compliant databases; import/export procedures for dBase IV and LOTUS 1-2-3 are included with TIMELINE Version 6.1.

159. TIMELINE® supports dynamic links with other Windows applications by means of Object Linking and Embedding (OLE).

160. Figure 7.2 shows a screen view of the example discussed in Annex IV. This is a standard "Gantt" view showing summary tasks, in three levels of hierarchy, and detail tasks. Here, "UNIT A" is at the top of the hierarchy, "RECALL", "COLLECTIVE TRAINING" and "EQUIPMENT REPAIR" are on the middle level and "MODIFY OK EQUIPMENT" is on the lowest level of summary tasks. Such tasks as "MODIFY OK EQUIP", "transport A to B" and "transport B to A" are detail tasks.

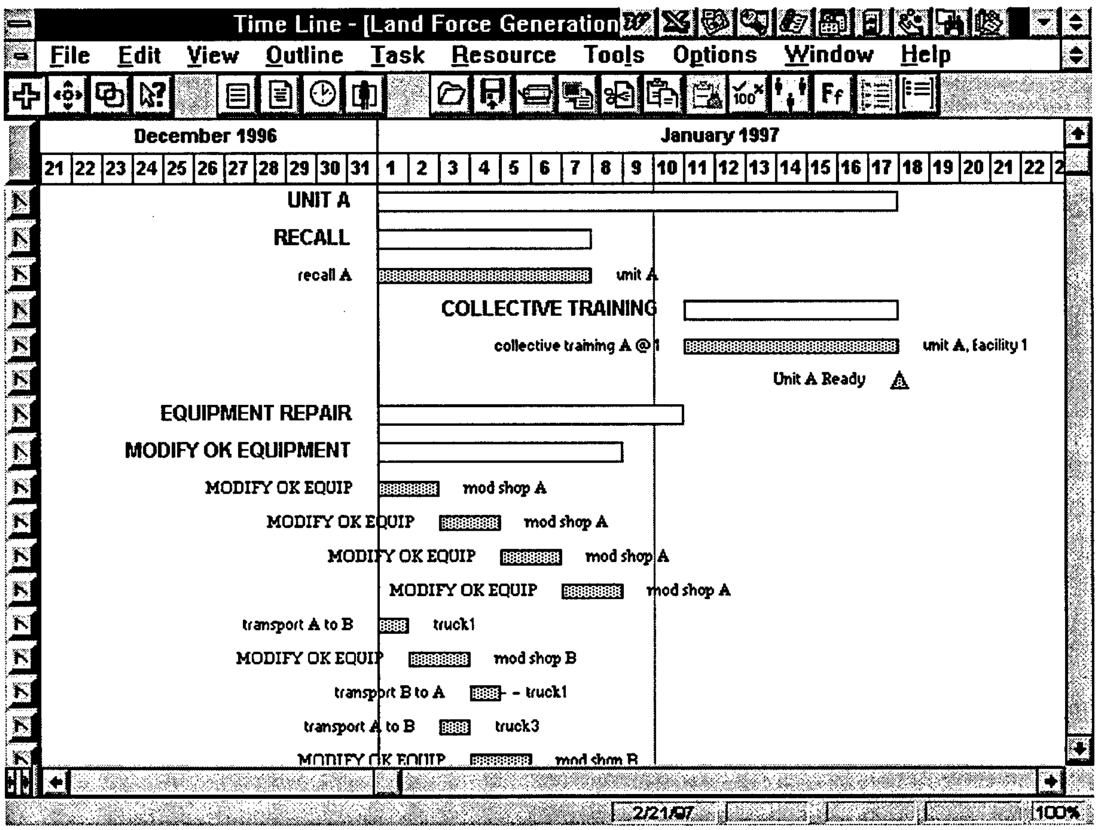

Figure 7.2: A screen view from SYMANTEC◆ TIMELINE

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CHAPTER 8

COST ESTIMATION OF READINESS OPTIONS

8.1 BACKGROUND

161. Managers of defence departments and armed forces are motivated to reduce budgets and to glean greater efficiency from spending on military capability. Thus, the art and science of cost estimation is of importance because it provides the basis for investigating ways of becoming more efficient. By exploring cause and effect relationships in spending patterns, managers can improve the return on public money invested in military capability.

162. More specifically, cost estimation of readiness options is of interest since cost estimation can provide a means for identifying areas of potential cost reductions. For example, reduction in the cost of operations and maintenance, training, logistic support and infrastructure might be derived from judicious cost analysis of readiness options.

8.2 ACTIVITY-BASED COSTING

163. Intuitively, an "activity" is something that must be done in order to accomplish an objective. In corporate circles, an "activity" describes the way an enterprise employs its time and resources in order to achieve corporate objectives. In technologically advanced organisations, it is economically valuable to model cost effectiveness in terms of activities because traditional accounting methods fail to correctly attribute the relative value of human resources to specific "outputs" in organisations where technology contributes significantly and in varying degrees to the outputs. A greater proportion of indirect costs (overhead) including technology costs and information processing costs now contributes to the total cost of maintaining and deploying armed forces than it ever did before. For this reason, many defence departments are moving toward activity-based costing.

164. Beyond the issue of attributing overhead costs to outputs, ABC provides a means to relate performance measures for activities at each stage of a process

to the ultimate outputs and thereby to enable programs for continuous improvement of processes. A resource and activity-based model of an organisations' inputs, processes and outputs provides a means of predicting future consequences of decisions. In this context, if the "output" is taken as capability within a given response time, then ABC is a useful tool for analysing the cost effectiveness of readiness-related processes and decision-making in defence organisations

165. Activities currently form the foundation of many cost management systems as businesses and government organisations are moving toward activity-based costing. Successful implementation of activity-based costing has helped various organisations to improve their work processes, to identify cost drivers and to control costs. Moreover, implementation of activity-based costing has given managers the information they need to improve their operational and strategic decision making.

166. In the public sector, it is useful to define an activity as "an element of work which turns resources into outputs". In the context of readiness evaluation, it is natural to describe both steady-state capability maintenance processes and capability surge processes in terms of "activities" where "outputs" are defined military capabilities that satisfy prescribed task standards.

167. Activity-based cost analysis can be used to identify any parts of operational or support processes that do not add value to a final product. For costing readiness options, ABC can be used to analyse the cost of maintaining and surging capabilities and consequently to provide knowledge of where and how resources are being consumed. Current or proposed consumption of resources can then be rated against planning priorities and adjustments can be made to improve the effectiveness of budgetary allocations.

168. ABC costing involves detailed breakdown of the final outputs into the various activities that contribute to them. For readiness costing, this breakdown can use capability-based plans as a starting point. ABC analysis then determines why resources are consumed to complete individual activities. The "whys" of ABC are known as cost drivers. The role of the cost analyst is to collect and allocate direct and indirect costs to individual activities, using these cost drivers.

8.3 THE IMPACT OF POLICY

169. It is instructive to consider the time and cost impact of policy. Policy measures that change activity rates or resource capacities will have a significant impact on readiness both from a time and cost point of view. Consider Figure 8.1 which illustrates the potential effect of a policy measure. A policy measure can have impact on activity rates and resource capacities both during the steady state and during surge periods. Changes in activity rates and changes in resource capacities will cause changes in the length of surge periods, as well as changes in capability maintenance activities during the steady state.

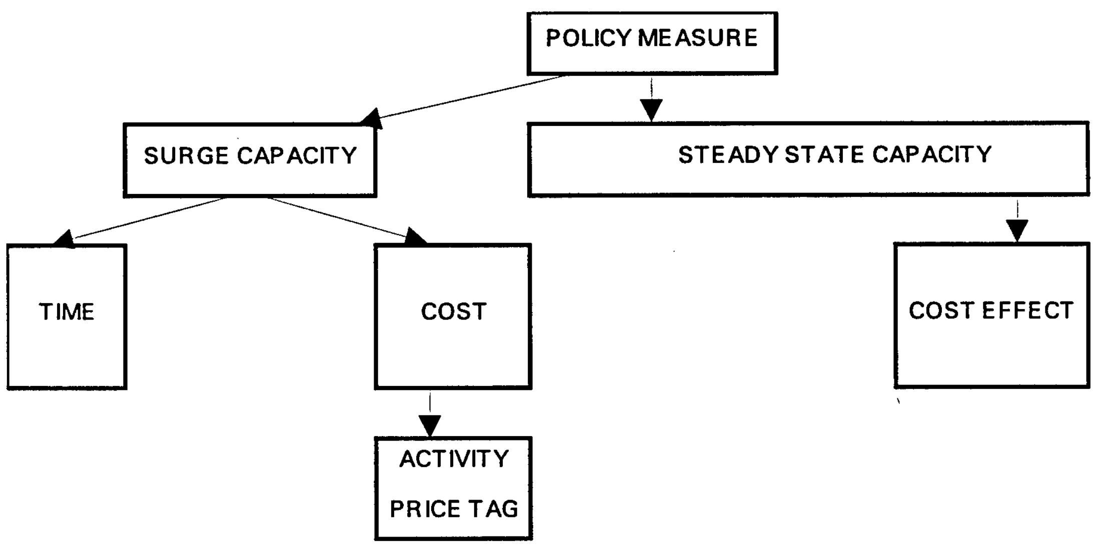

Figure 8.1: Readiness Policy and Cost Relationship

170. Suppose that either an activity rate has been lowered or a resource capacity has been reduced. For example, if the number of mechanics in a vehicle repair facility is reduced then the number of vehicles that can be repaired in any given interval is reduced. If the annual number of training courses for mechanics is reduced then the

number of qualified mechanics may ultimately be reduced. If fewer mechanics are available, then the rate at which vehicles can be repaired during a surge interval will be lowered. In such cases, resource consumption and utilisation has been reduced and consequently O&M spending will be reduced along with personnel costs and overhead costs.

171. From the timing point of view, clearly, the lowered repair rates will result in a longer surge interval for vehicle repair. However, there is another effect of lowered repair rates that will tend to drive up the surge time for vehicle repair. If the vehicle repair rate is sufficiently low during the steady state, then there might be a need for even more maintenance activities during the surge phase than there would have been otherwise.

172. If the overall time interval to complete the surge processes for all surge activities is not delayed by reducing the number of mechanics, then, reducing the number of mechanics might be an acceptable way to reduce costs since the delay on completing vehicle repair will not lengthen the overall surge duration.

8.4 SOME GENERAL PRINCIPALS OF COST REDUCTION

173. Typical readiness options take the form of resource or activity trade-offs. Managers are motivated to find innovative ways of achieving the same or improved readiness standards while using the same or lower levels of resources. In many cases, the cost of using internal resources to provide a service must be compared to the cost of contracting out; or the cost of purchasing equipment or constructing a building must be compared to the cost of leasing comparable equipment or facilities. Transportation and training options are other areas of potential cost reduction.

174. At the highest levels of decision-making, policy choices are made to prioritise capability requirements and allocate resources; decisions about capital investment in infrastructure and military assets are also made at this level. Cost estimation which relates to capital investment is typically more complex than cost estimation which does not. Often, sophisticated economic models must be used to fully estimate the effect of changing capital assets or capital investment. For example to gauge the impact of closing a military base on the economy of the region it is located in requires economic modelling.

175. By determining steady-state strength and proficiency of capabilities, policy decisions determine (either explicitly or implicitly) potential activities

which could be undertaken in order to bring capabilities to prescribed task standards for operations. Policy may, in fact, permit a number of potential surge processes. In any case, infrastructure and resource-related policy decisions bound the shortest possible response time and the maximum possible output of all potential capability surge processes.

176. Policy decisions, by establishing infrastructure, assets, resource levels and activities, have a "cost effect" insofar as they determine the steady state costs of maintaining, training, operating and managing the armed forces. Furthermore, by determining the activities that must be completed and the rate at which each of the activities can be completed, policy decisions determine the cost of readiness surge processes.

177. Cost estimation can provide guidelines on the economic trade-offs of closing facilities: if operating costs at facilities remaining open plus new costs resulting from closure of facilities is less than the O&M cost of all the facilities remaining open then it is economical to close the facilities. New costs might include transportation costs (to move resources to alternate facilities) or increased operating costs of facilities that remain open. There would typically be a trade-off between capability and time with closure of facilities and the time consideration might rule out closing a facility.

178. Cost estimation for the impact of a facility closure is an example of cost estimation for the impact of a capacity change. In general, lowering capacity can save money but lowering capacity also lowers the rate of productivity and therefore lengthens the time required to reach operational capability levels during a surge process.

179. Another frequent consideration for cost reduction is alternate service delivery; i.e. contract services or rent infrastructure from private sector sources or other government agencies. On an as-required basis, within the constraints imposed by the market place, capacity might be increased by leasing/hiring increments to bring production rates up to the needed levels as operations require.

180. Training is an area of interest for investigation of potential cost reduction. Electronic simulators and trainers can be used to calibrate performance and learning as a function of training activities. Studies have indicated that calibrated training on electronic trainers in the early stages of the learning process is better than un-calibrated training on operational systems. Not only does the use of electronic training systems improve the efficiency of training but the utilisation of actual equipment can be reduced. As a consequence, training time can be reduced and the life-cycle of cost of

actual equipment can be reduced. Expenditure of consumables such as fuel and ammunition are also reduced.

181. For many applications, it is clear that overhead costs will decrease with down-sizing. Therefore, in such cases, we can assume for purposes of estimation that overhead costs will, at worst, remain the same in order to get a preliminary estimate of cost reductions. Nevertheless, there are certain overhead costs that might be easily estimated, e.g. office space or storage space.

182. Intuitively one expects that lower readiness requirements should lead to lower defence spending. The principal means by which spending would be lowered is by scaling down operations. That is, fewer facilities, fewer personnel, lower resource consumption, lower maintenance levels, lower training levels should lead to lower O&M costs and lower overhead costs. The trade-off however, would be longer readiness times and lower steady state capability. Nevertheless, it might be that for some readiness situations, getting ready faster would actually save money. That is, critical path analysis might reveal ways of getting things done more efficiently in such a way that time saved is proportional to money saved. In any case, the methodology of CPA can be applied to existing plans to test their feasibility and efficiency and can in many cases reveal more efficient ways of accomplishing readiness.

8.5 TERMINOLOGY OF COSTING

183. The following terms are used in the discussion of cost estimation. They are introduced here as background information and will be elaborated upon as required:

sunk costs

costs that are unavoidable because they cannot be changed no matter what action is taken, sunk costs are not relevant to most decision making processes.

non-recurring cost

costs incurred on a one-time basis

full cost

the sum of all direct and indirect costs of an activity; full costs include all personnel costs, all related fixed and variable operations and maintenance costs, and allocated costs, such as depreciation.

variable costs

costs which change, in direct proportion to changes in the related total level of activity or volume.

fixed costs

costs that remain unchanged, in total, for a given time period despite wide changes in the related total level of activity or volume.

direct costs

costs that can be precisely attributed to producing or providing a good or service; these costs will increase or decrease in direct proportion to a change in the level of activity; such costs are typically straightforward to identify and measure.

indirect costs

costs that cannot be precisely attributed to producing or providing an additional good or service.

incremental costs

additional costs incurred by an organisation, above normal operating costs, resulting from added requirements; these costs will result in a requirement for additional resources or reallocation of additional resources.

standard costs

national average costs, based on several years of historical data, of a particular resource, expressed per unit of activity such as "person-year" for personnel and "per flying hour" for aircraft.

8.6 TYPES OF COSTS

184. When analysing a number of options, there may be some resources that remain the same whatever the option. These resources can be considered irrelevant in the costing context unless it is required to determine total cost for an activity. Such resources should be excluded from the costing effort in order to focus on the relevant variable costs.

185. If a change in an activity does not change certain costs these are known as **fixed** costs. If a change in an activity requires use of additional resources, the costs related to these resources are known as **incremental** costs. Incremental costs can be **fixed** or **variable** in nature. When comparing alternatives, incremental costs are of prime importance.

186. Costs will either have a **direct** or **indirect** relationship to a particular good or service. Direct costs can be directly attributed to producing or providing a good or service, and will increase or decrease in direct proportion to a change in level or activity (e.g. basic pay). Indirect costs on the other hand are those costs that cannot be precisely attributed to producing or providing a good or service. Indirect costs are those that cannot be effectively linked to an individual's rank, but can be incurred for each regular force person (e.g. state-funded health care costs).

8.7 METHODS FOR ESTIMATING COSTS

187. Cost estimation is as much an art as a science, especially when compared to financial accounting. There is no absolute method for determining costs. However, any sound costing approach must be logical and the constituent cost data that it uses must be valid and verifiable.

188. There are four main cost estimating methods in general use: the engineering method, the parametric method, the analogy method and the expert opinion method. The use of a specific method varies with the amount and reliability of available data. Furthermore, more than one cost estimating method may be used in the preparation of estimates for decision-making purposes. A brief description of each of the methods follows:

Engineering Method: (bottom-up method) requires that the system be divided into segments and that the cost of each segment be estimated. The segment costs are then combined together with any integration costs to arrive at the total cost. A major

limitation of the integration method is that it requires extensive knowledge of the system. Also, it requires knowledge of the development and production processes. For new technologies, detailed knowledge required for the complete engineering method is not always available.

Parametric Method: makes use of formulae that express general relationships. These are derived from statistical analysis of past projects and relate costs to one or more technical or physical characteristics. This method depends intimately on the establishment of valid relationships between costs and characteristics. Lack of data may limit the use of this technique.

Analogy Method: assesses the cost of a project as a whole, or its constituent parts, by comparison with previous projects, allowing for differences in type, complexity, technological change or scale. This method is in essence an extrapolation from the past rather than a statistical or engineering attempt to establish a formula. This method requires considerable expertise and judgement skill and assumes that similar systems are known in some detail.

Expert Opinion Method: draws upon the subjective judgement of an experienced individual or group. Estimates based on this Method usually lack detailed rationale and analysis and subsequently lack a good level of confidence. This method should not be used if scientific methods are possible.

189. An activity-oriented approach to readiness evaluation lends itself readily to the engineering method and the parametric method, although the other two methods might be useful in some cases. For example, in cases where only direct operating costs or incremental costs need to be considered, the engineering method and the parametric method are sufficient for many cost analyses. However, if previously untried training options or equipment maintenance options are being costed, either of both of the analogy method and the expert opinion method might be needed in order to assemble enough information to make a reliable cost estimate.

8.8 COST ESTIMATION CONSIDERATIONS

190. Cost estimation is a time-consuming and complex process requiring access to a wide range of information and techniques. Cost estimates, like all types of estimates, are approximations and therefore carry an inherent uncertainty in their accuracy. Approximations are often based on statistical analysis of data or a mathematical model. Consequently, approximations can be refined by some combination

of enlarging the sample size of the data and increasing the sophistication of the statistical analysis or models used to make the estimate.

191. Both enlarging the sample size and increasing the sophistication of the analysis require additional effort and might result in an insignificant improvement of the approximation. The final degree of costing precision required depends upon the purpose of the estimate and the ease of identifying the costs involved. To determine the level of detail and accuracy required, a cost-benefit analysis can indicate the relative worth of refining the estimate compared to the cost of the resources required to make the refinement.

192. When developing the full costs of options, the complex issue of **cost allocation** has to be addressed. This is the process that is required to attribute overhead and indirect costs to appropriate activities in a way that quantitatively and meaningfully links such costs to resource consumption and outputs.

193. The allocation of common costs is usually required for managerial purposes such as recovery and planning decisions. The allocation process involves three principal steps:

- accumulating the costs related to the system, activity or operations;
- identifying the recipients/consumers of the allocated costs; and
- selecting a basis to relate the costs to the recipients/consumers.

The last step is the most difficult. Typically, the allocation basis is selected on empirical grounds that serve the main intention of the cost estimate.

194. Cost estimation is often based on statistical analysis of cost-related data. The uncertainty inherent in statistical analysis gives rise to a number of typical errors:

- double counting - including the same cost element in more than one portion of the estimate;
- omissions - overlooking costs that apply to the estimate;
- hidden costs - costs that result from ill-defined categories, nondisclosure of certain costs or improper allocation of overhead;

- Spill over costs - costs that result from secondary effects not considered.

8.9 COSTING CONCEPTS

195. There are two useful concepts to guide cost estimation processes:

- **Relevant Costs** - include only those costs that are relevant and consequential. For example when comparing the cost of buying and operating new equipment against repairing and keeping old equipment, the initial cost of the old equipment has no bearing on the situation; however, if the old equipment can be traded or sold to reduce the cash requirement for new equipment then it becomes a relevant cost.

- **Control over costs** - resource managers seldom have complete control over all the costs of all the resources at their disposal; the cost analysis must distinguish between what costs are controlled by the managers involved in the business and those costs that are attributable to the business but over which there is no control.

8.10 COSTING APPROACHES

196. The costing approach that is used should be considered carefully so that any options analysis conducted later can conform to the selected approach in the interests of consistency and fairness. The major approaches are the following:

- **Incremental Cost Approach**: the incremental cost approach seeks to identify costs that are directly and precisely attributable to the activity or process being costed; this approach is most commonly used in situations where the activities have clear organisational boundaries and all of the resources can be controlled. The incremental cost approach can be used to support efforts to reduce resource inputs to achieve the same level of outputs; overhead costs such as base support costs are not considered relevant, unless they can be specifically identified with the area being examined and are known to vary with changes in the activities.

- **Operating Cost Approach**: the operating cost approach takes a wider view of the options at hand seeking to cost them in greater detail; this approach will identify all costs that impact on the organisation at large regardless of who may exercise control over those costs; this approach is more suitable to larger and wider reaching cases and includes an examination and exploration of fixed and overhead costs to determine their relationships with the organisation to see if anything can be done about them when

finalising options; however, the distinction between costs that are rolled up for analysis and the concept of consequential or avoidable costs must be maintained; i.e. costs used for decision making purposes must be relevant and controllable; for this reason, capital costs such as depreciation and attrition are not considered in this type of analysis; this approach is suitable in situations where a complete function or activity is being considered for privatisation.

- **Full Cost Approach**: the full cost approach identifies all costs associated with the organisation, including allocated overheads and capital related costs; this approach is useful in large scale case analysis where it is important to understand the relative value of competing options and life cycle cost issues.

8.11 COST CATEGORIES

197. The cost categories represent the resources that are used. These categories are further sub-divided into direct and indirect costs. Many of these costs can be extracted form the cost factors manual.

Personnel Costs These are the costs of all the relevant military and civilian personnel resources further subdivided based on who controls the cost. For example, civilian personnel costs are budgetary and probably controllable to the analysis team, whereas direct military costs are controllable but not within the team's budgetary control; different managers will be impacted by changes to personnel resources.

Equipment Costs These include direct and indirect costs of operating equipment used within the activity or business boundaries, further subdivided based on who controls the costs. For example, the business analysis team may be able to control the direct operating and local maintenance costs for a major piece of equipment but the major repair and overhaul costs are controlled by someone else. In such cases, the fact that different budget managers pay for different aspects of the maintenance does not change the point that savings will happen if the equipment is eliminated - it is a matter of how the savings will be captured and recorded.

Facilities Costs Facilities costs are sub-divided based on control over the costs. Particular attention should be exercised in identifying if there are any real savings or costs associated with the use or change in use of facilities. Facilities costs are often sunk costs that will not result in any true savings, except in cases where the options deal expressly with facilities issues.

Other Costs or Offsetting Revenue Include costs that do not fall neatly into one of the other resource categories or to capture any direct and indirect revenues that may be associated with options.

Identifying Relevant Resource Costs

198. The following bullets provide the framework for identifying resources to consider for costing:

- determine who is affected by the alternatives both directly and indirectly
- determine what specific equipment, is required to accomplish the tasks
- determine what facilities are used to locate individuals and equipment

199. Costs will either have a direct or indirect relationship to a particular good or service. Direct costs can be directly attributed to producing or providing a good or service, and will increase or decrease in direct proportion to a change in level or activity (e.g. basic pay). Indirect costs on the other hand are those costs that cannot be precisely attributed to producing or providing a good or service. Indirect costs are those that cannot be effectively linked to an individual's rank, but can be incurred for each regular force person (e.g. provincial health care costs).

200. There are three cost categories as outlined in the cost factors manual: military and civilian personnel costs, equipment operating costs and facility operating costs. This breakdown provides the framework for analysing the type of resources involved in a particular cost analysis. Each category can have fixed and variable costs as well as direct and indirect costs, that must be considered in some manner during the cost analysis.

Personnel Costs:

determine changes in the numbers of personnel

determine changes in the rank/classification of personnel

determine changes in the mix of personnel (regular vs. reserve, military vs. civilian)(especially relevant to indirect costs)

determine changes in the location of employment of personnel

Equipment Costs:

Typically this is determined by vehicles, weapon systems, radar and major information systems. The analysis of how the equipment identified will be affected is similar to personnel in that there are fixed, variable and non-recurring cost components. Thus, for example, for mobile equipment, POL is generally considered to be a purely variable cost whereas Spares, Repair & Overhaul (SR&O) costs are often a function of time, activity rate and type of usage and are partly fixed costs. To determine equipment costs the following must be considered:

determine changes in the quantity of equipment;

determine changes in the activity rate of the equipment;

determine changes in the type of equipment being used;

determine changes in the use of the equipment;

determine changes in the maintenance of equipment.

CHAPTER 9

RESULTS, CONCLUSIONS AND RECOMMENDATIONS

9.1 COMPARISON WITH THE RAND "IDEAL" OF READINESS ASSESSMENT

201. Recall from §2.2, the eight characteristics of an "ideal" readiness assessment method. Consider the R-C CPA methodology in terms of each of them:

- **reflect what units and forces can do, not just what they have:**

  because the R-C CPA methodology is based on the description of operations in terms of activities, resources and timing, it does reflect what units and forces can do;

- **be practical (i.e. non-disruptive, inexpensive and understandable):**

  military plans are written in terms of activities, resources and timing and therefore the R-C CPA methodology is practical insofar as it conforms to planning practices; the methodology can incorporate into readiness assessment as much detail as planners give; conversely, the methodology can be used to pinpoint aspects of plans that require more detail in order to be properly evaluated; low cost software is widely available commercially to implement the methodology; the only additional work that the methodology requires above the usual effort spent on planning, is the creation of an activity/resource/time database; however, if planners were to move away from *paper*-based plans to *data*-based plans, there would be no additional work and the resulting flexibility in amending, analysing, evaluating and describing plans would be very significant;

- **be objective and verifiable:**

  the R-C CPA methodology uses activity-oriented descriptions of operations plans together with estimates of time and resource requirements that can be rigorously tested using quantitative and statistical methods; results of exercises and operations can be used to test and verify the assessments made by the methodology; corrections and refinements to the estimates can be made based on the analysis of test results;

- **reveal the robustness of posture across scenarios with varying and somewhat unpredictable conditions within scenarios:**

  the R-C CPA methodology can be applied in a parametric way to varying scenarios with appropriate adjustments to the activities, the time estimates and the resource estimates; stochastic elements based on the uncertainty of scenarios can be introduced by means of a stochastic scenario generator and analysed by means of statistical analysis of the outcomes from R-C CPA;

- **provide useful feedback to the providers of elemental data;**

  the R-C CPA methodology returns a predictive evaluation of readiness together with an objective justification of resource requirements to the providers of data; performance measurement systems can use the results of the R-C CPA methodology to identify shortfalls and inefficiencies in the levels and allocation of resources; providers of elemental data typically fit into performance measurement schemes at some level, and therefore can use R-C CPA to justify and rationalise their activities;

- **permit comparisons of status from one year to another:**

  the R-C CPA methodology provides quantitative assessment of the time required to meet quantitative benchmarks; year-by-year comparisons of timing and benchmarks can be readily accomplished using the methodology;

- **reflect the transition from peacetime to wartime;**

  the R-C CPA methodology supports activity-oriented descriptions of force generation processes; by aggregating an activity-oriented description the transition from peacetime to wartime from all relevant plans, the transition from peacetime to wartime can be modelled;

- **permit evaluation of trade-offs:**

  the R-C CPA methodology enables trade-offs, in terms of alternative activities, resources and benchmarks, to be evaluated and compared in terms of feasibility, efficiency and cost.

202. Thus, the proposed R-C CPA methodology compares favourably with the "ideal" characteristics put forward by RAND.

9.1 ACHIEVEMENTS

203. The ST reports a number of achievements:

- **shared representative data, briefed existing methods:**

  the shared experience and data of participating nations in the ST was used to build the readiness paradigm and the readiness evaluation framework; experience with existing methods and models and their shortfalls led to the development of the R-C CPA methodology for readiness assessment;

- **framework for CERs:**

  the activity-oriented framework for readiness evaluation led naturally to an activity-based cost framework for cost estimation of readiness options; because activity-based costing links resource utilisation and consumption directly to outputs, the cost-effectiveness of capability generation can be analysed using activity-based costing;

- **identified deficiencies of unit level methods**

  requirements at both the national level and the alliance level for readiness evaluation methods revealed a number of deficiencies; principal among these was the deficiency of current asset counting methods to predict capability over time;

- **designed spreadsheet for effort/cost estimates:**

  summation estimates can be made for cost and effort by using a spreadsheet; a number of considerations about precedence relationships and resource constraints indicate that these estimates are probably coarse; however, they are indicative of the relative worth of readiness options and can be used to filter attractive cases for more careful assessment;

- **proposed general purpose methodology for readiness evaluation:**

  it has been shown that R-C CPA provides a solid basis for evaluating readiness; it can be used to evaluate joint readiness and flexible readiness; the proposed methodology compares favourably with "ideal" characteristics proposed by RAND for readiness assessment methods;

- **gave a research action plan in the form of recommendations for future work:**

  the research action plan was given in the form of recommendations for future work; these recommendations appear below in §9.5

9.2 MILITARY BENEFITS

204. The ST reports a number of military benefits. The work of the ST has put forward a comprehensive methodology for :

- **cost effectiveness studies:**

  the use of activity-based costing coupled with R-C CPA enables careful assessment of the cost effectiveness of readiness alternatives and policy options;

- **readiness evaluation:**

  R-C CPA enables careful analysis of response time and benchmarking for readiness; it provides a basis for testing and validating timing estimates as well as estimates for resource requirements;

- **policy evaluation:**

  the proposed methodology can be applied parametrically across a spectrum of scenarios in order to evaluate policy options;

- **cost/time trade-off analysis:**

  the relative worth of options in terms of response time and cost can be evaluated using R-C CPA and ABC; attractive options can be screened using the summation estimate spreadsheet;

- **resource management:**

  the methodology supports careful analysis of resource requirements and expected resource utilisation by specific activities; this enables a predictive approach to resource management which can be used to improve the efficiency of budgetary spending

9.4 ENUMERATION OF MAIN POINTS

205. The ST provides a list of its main findings:

- **refined definition of readiness:**

  the ST put forward a "refined" definition of readiness that is consistent with existing NATO definitions of readiness-related terminology but which is quantifiable enough to form the basis of methodology to evaluate readiness;

  definitions for joint readiness and flexible readiness follow in a logical and consistent way from the refined definition.

- **readiness paradigm:**

  a generic force generation process was put forward as a useful basis for deriving methodology;

- **spreadsheet estimation of time and cost:**

using the paradigm, a spreadsheet was designed for calculating summation estimates for the response time and cost of readiness options;

of themselves, such estimates are coarse, however, they can be used comparatively to rank the relative worth of options;

they can be used to screen attractive options for readiness that merit more careful analysis;

the paradigm points to the need to include transit time for joint training into the response time;

- **readiness framework:**

an activity and benchmark oriented framework for readiness evaluation was derived by generalising from principles of unit level readiness to readiness of a formation;

the framework focuses on response time as the primary measure of readiness but allows other indicators of readiness to be linked to time by means of benchmarks;

the framework supports analysis of readiness in terms of analysis of resource / time / activity requirements to achieve benchmarks within evaluated response time;

- **risk analysis:**

the framework supports risk analysis as sensitivity analysis with respect to resource / time / activity changes;

- **readiness evaluation:**

the ST proposes the use of resource-constrained critical path analysis as the basis for readiness evaluation;

relatively low cost software is available for implementing R-C CPA;

the ST recognises that R-C CPA alone is not sufficient to optimise all of the resource allocation sub-problems inherent in military readiness;

resource allocation sub-problems can be dealt with by suitable sub-procedures within the overall readiness framework subject to the umbrella R-C CPA methodology;

the ST recognises that the algorithmic complexity of R-C CPA may render it impractical for large problems, where "large" might not be adequate to address some actual situations;

however, by the tactic of optimising tractable sub-problems and aggregating outcomes from optimised sub-problems into larger problems, a good estimate for the optimal solution can be found;

furthermore, by finding an appropriate level of detail to describe activities, a manageable scale can be brought to readiness assessment problems;

- cost estimation:

use of activity-based costing fits naturally into the readiness evaluation framework;

activity-based costing enables direct cost relationships to be drawn between resources and capabilities by means of activity-oriented descriptions of force generation processes;

the relationship between policy and cost can be established by analysing the impact of policy decisions on steady state capacity and surge capacity;

as a general principle, cost reductions are achieved by lowering activity rates or lowering resource capacities;

R-C CPA can be used to find ways of achieving benchmarks more efficiently thereby allowing fixed readiness standards to be maintained and surged at lower cost.

9.5 FUTURE WORK

- **sustainability question:**

the ST has dealt primarily with readiness, leaving sustainment as a topic for future work; however, sustainment can be described in the time / resource / activity framework of readiness and therefore, much of the work already done for readiness assessment can be adapted to sustainment with the addition of some additional considerations that deal with rates of cycles of re-supply activities;

- **build testbed / demonstrator:**

  it appears that there is merit in attempting to test and demonstrate the methodology; this is already being done Canada, and at SACLANT;

- **evaluation of standards:**

  the relationship between task standards and readiness activities needs to be rigorously tested so that cause and effect relationships between such things as training and maintenance activities can be directly linked to their contribution to task standards and hence to capability;

- **evaluation of indicators:**

  test and evaluation and performance measurement are typically based on a small set of indicators that are intended to reveal the general state of proficiency in a unit or formation; the relationship between specific indicators and general proficiency needs to be rigorously studied to determine what, if anything, is not well correlated with indicators being used and if there are better indicators that should be used instead.

ANNEX I

TERMS OF REFERENCE

I. Background

1. The changing role of military force is driving reviews of policies for Readiness and Sustainment (R&S). Nations must now anticipate a blend of changing low and mid intensity situations in addition to the possibility of protracted conventional high intensity conflict. Planning methodologies are required that can quantify future force R&S options and identify the most cost effective options. The Exploratory Group (EG) identified gaps in methodologies for R&S assessment as well as the pressing need for higher management to evaluate trade-off analyses. As recommended in the EG meeting report, the Ad Hoc Working Group (ST) will focus on flexible readiness and joint readiness in the mid term.

II. Objectives

2. The ST will review and share existing approaches and then recommend and develop methodologies to assist policy makers and planners. The focus will be on two key problems: (1) flexible readiness - to assess cost trade-offs between peacetime options and transition to wartime readiness; (2) joint readiness - to assess economies of joint, multi-national and coalition forces.

III. Aim of Study

3. Over a 24 month time frame, the ST will aim at:

- sharing data sets and existing methodologies;
- deriving Cost Estimating Relationships (CER) models to establish viable peacetime readiness;
- identifying gaps in existing methods;
- examining national level methods to assess flexible readiness;
- deriving an integration process and methodology to assess joint readiness;
- developing a research action plan to support recommended methodologies.

ANNEX II

FINDINGS AND RECOMMENDATIONS OF THE EXPLORATORY GROUP

1. This section summarises the findings and recommendations of the Exploratory Group as reported in Reference 1. The EG met in October 1993 to undertake a comprehensive survey of the R&S problem, to investigate the need for and potential utility of an "Ad Hoc Working Group" (in later terminology a "Specialist Team") to devise methodology for analysing the problem.

1. Origin

A. Background

2. Reference 1 noted that several member nations were, at that time, in the process of reviewing policy on Readiness and Sustainment (R&S). The review of R&S policy continues in many nations. The EG noted that the review process is driven by the rapidly changing role of military forces in the new world context:

3. "Mission profiles have changed and new types of joint missions are more likely in the future; force readiness and sustainability can no longer be based on the possibility of conventional protracted high intensity conflicts but a blend of changing low and medium intensity situations."

4. The EG made particular note of the difficulties on readiness policy formulation imposed by economic constraints. Methodologies are required to help higher management in carrying out their planning. More importantly, integrated decision support tools are required for predicting R&S levels over time horizons. Because of the economic constraints, setting realistic readiness and sustainment goals and identifying support requirements has become a major decision problem.

5. The EG meeting pointed to gaps in Operational Analysis methodologies for R&S assessment and decision support but also brought forward the requirement to facilitate trade-off analyses required by higher management. The EG recommended that the ST should focus its work on flexible readiness and joint readiness

in the mid term. Definitions for flexible readiness and joint readiness problems were put forward:

Problem 1: Flexible Readiness

In order to assist policy makers and planners, a methodology is required to enable cost trade-offs to be examined between peacetime readiness states and the process by which forces are (rapidly) raised to their required readiness for employment. The methodology should not be restricted to the reshuffling of existing resources but should be capable of addressing the impact of new technologies on the surge process.

Problem 2: Joint Readiness

Advice is required on ways in which the readiness of units and small formations combine to produce readiness for the overall force. Of particular concern are Joint, Multinational and Coalition Forces.

B. Military Benefits

6. The EG noted the need for a comprehensive analytical framework for conducting cost effectiveness studies relating the various readiness levels and sustainment criteria to the expected cost of operations and support. The EG went on to recommend that the ST should foster the development of a methodology and eventually a range of compatible models to provide the military with a better capability to:

- define a feasible set of tasks for units and formations and to determine realistic peacetime readiness levels;
- forecast cost-effectiveness of tasked formations and to determine cost saving measures that could be effected without lowering R&S parameters;
- conduct practical trade-off analyses of force generation options;
- take a global integrated look at force performance, including the formation of joint, coalition forces;
- commit resources in an economical way by avoiding double counting;
- enhance existing R&S reporting systems in an evolutionary manner.

7. The EG also recommended that the ST should aim at providing each country with methods for addressing domestic problems in addition to an approach for dealing with joint, multinational readiness problems.

II. Objectives

8. It was the proposed that the ST would first review and share existing approaches. Subsequently it would recommend and develop methodologies to assist R&S policy makers and military planners. This joint method sharing and research activity was to focus on the problems of flexible readiness and joint readiness, as defined above. The EG recommended that sustainment and in-theatre employment questions would not be addressed, initially.

III. Definition of Terms

9. The EG put forward definitions of readiness terminology it had used:

A. **Readiness**

Readiness is the ability of military forces, formations, units, weapons systems or equipment to accomplish a given set of tasks for which they were designed. Readiness includes the ability to deploy and employ units within an acceptable time delay.

B. **Readiness Level**

Readiness is measured in terms of operational capability and response time. A readiness level identifies the specific operational capability and response time required to perform a task.

C. **Sustainment** (or sustainability)

Sustainment is the ability to support deployed forces, formations, units, weapons systems or equipment at a set level over a period of time.

D. **Sustainment Criteria**

Sustainability is assessed in numbers of days. Sustainment criteria are measures of the expected casualty rate and the expected consumption rates for various resources. R&S policy calls for the assignment of sustainment criteria for all units, and these criteria are established to cover low, medium, high or peacetime levels of operational intensity.

E. **Levels of Operational Intensity**

F. **CERs**

Cost estimating relationships are quantitative functions or measures for costing options from cost elements making up a total cost.

G. **Assessment Methods**

Information systems, data analysis tools, simulation techniques, war games used to relate R&S parameters with one another. A range of methods are in use:

- available assets (personnel, equipment, training, supplies, stockpile)
- functional evaluation; procedural exercises
- mobilisation planning/exercises
- force deployment planning/feasibility studies
- simulation and war games for combat/support

H. **R&S Reporting System**

The process of collating, aggregating, assessing R&S of a formation and pinpointing the critical capability gaps for an entire force. Existing reporting systems mainly account for inputs, fill levels with limited emphasis on projected output from the training system.

I. **Integration-Aggregation** (for flexible and joint readiness).

While linking unit level performance and micro level CERs is fairly straightforward, their aggregation amounts to rolling up a complex and often ill-defined set of performance indicators to arrive at higher echelon formations status in terms of

R&S over a time period. Such a process leads to many problems: double counting, over-commitment of resources stemming from worst-case based plans; inconsistency in reporting (no common analytical-assessment framework); lack of robustness of some indicators. The time dimension is also a major problem, since most systems are input or snapshot based.

IV Aim of the Study

10. The EG foresaw that development of methodologies in support of flexible readiness and joint readiness problems would be achievable over a 24 month time frame. The EG advised that ST methods and recommendations should be made available by the end of 1995. The study to be carried out by this ST would therefore aim at:

- sharing relevant data sets and developed methods;
- investigating CER models and assessment methods to set up peacetime readiness levels in a cost effective manner;
- identifying gaps in existing methodologies;
- recommending methodologies used for flexible readiness at the national level;
- outline an integration process and recommend a methodology to factor in joint readiness aspects; and
- producing a research action plan to support the recommended methodologies.

V. Duration

11. Recommended 2 years

VI. Resources/Membership

12. Canada agreed to chair

VII Security Level

13. NATO Secret

VIII. Outside Participation

14. TBD

IX. Liaison

15. TBD

ANNEX III

OUTLINE PROGRAM OF WORK

Major Items:

- Review of existing methodologies
- Describe decision support requirements
- Develop a methodology to deal with flexible readiness
- Propose/Adapt Specific Methodologies
- Develop an integrated process to evaluate joint readiness of forces
- Propose a research action plan.

ANNEX IV

EXAMPLE ASSESSMENT OF ARMY REGENERATION CAPABILITIES

1 INTRODUCTION

1. In times of crisis, forces must be raised from their current state, to a state at which they are ready for operations. This overall process is called regeneration, build-up or surge and comprises a number of different processes, each of which may have constraints on throughput. Thus, although calculating the time required for a single unit to regenerate may be as simple as adding together the times required for a small number of processes, once resource constraints become significant then the scheduling problem rapidly increases in complexity as the number of units being regenerated is increased. Different types of constraints are likely to occur, some of which may be incompatible with the suggested method of solution.

1.1 AIM

2. The aim of this example is to show how the proposed approach may be used to solve a simple example problem. The problem is structured to illustrate a number of different types of resource constraints.

2 THE PROBLEM

3. The basic structure of the problem is shown in Figure 1. This shows that three types of assets are to be considered: Personnel, Equipment and Supplies. Personnel must be recalled, individually trained, linked with its equipment (which may have required repair followed by modification), collectively trained and then linked with its logistics supplies at which stage it is ready.

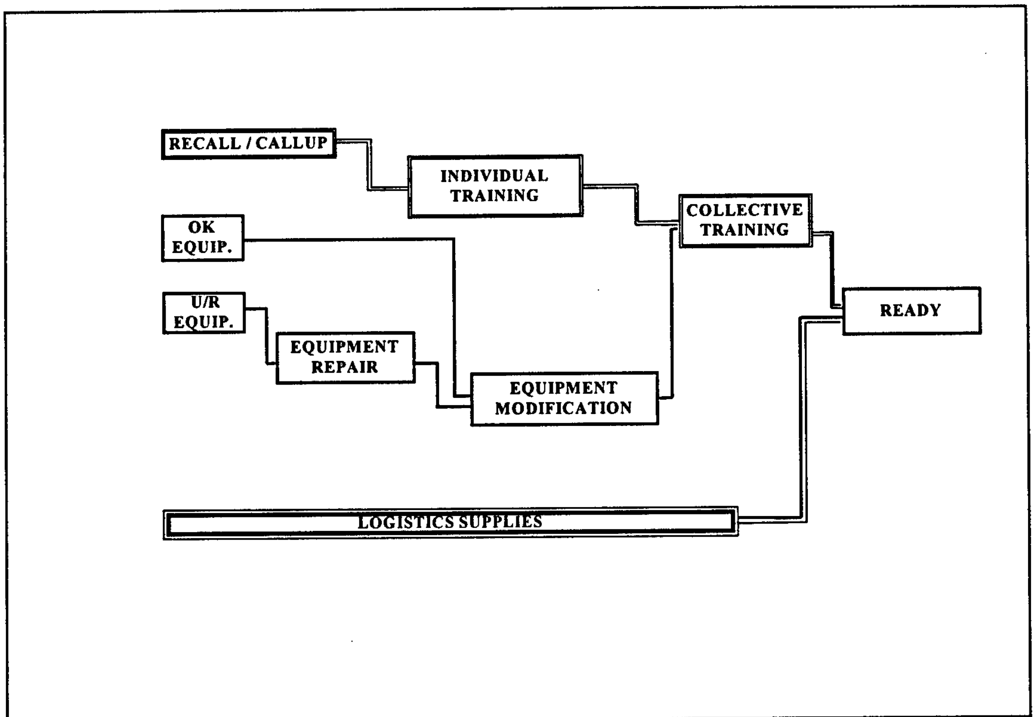

FIGURE 1 Army Surge Process

4. For this simplified example, and to test the methods by which it will be assessed, we consider four units A, B, C and D. Each comprises a war establishment of 1000 men with 100 equipments. Units A, B and C are of similar type with similar equipment each requires 1000 tons of logistics supplies which are interchangeable. Unit D has different equipment and requires 2000 tons logistics supplies which are not interchangeable with those of A, B and C.

5. Unit A is a high readiness unit with a peacetime establishment of 900 men and 80% of its equipment serviceable. Its manpower shortfall is to be made up by transferring 100 regulars from other duties, these men need no individual training. Units B, C and D are lower readiness units that need reservists to bring them to their war establishments. These reservists need individual refresher training, each unit conducts its own individual training. Once a unit has reached its war establishment with all its equipment repaired and modified (all equipments need modification) it requires collective

training at specialist facilities. Table 1 summarises the regeneration requirements of each unit.

TABLE 1.REGENERATION REQUIREMENTS

	UNIT			
	A	B	C	D
Personnel to be called-up/transferred (regulars)	100	-	-	-
Personnel to be called-up/transferred (reservists)	-	300	500	400
Time required for call-up/transfer of regulars (days)	7	7	7	7
Refresher training required by reservists (days)	-	7	7	7
Number of equipments needing repair	20	40	50	30
Equipment Repair Time (days)	5	5	5	5
Number of equipments needing modification	100	100	100	100
Equipment Modification Time (days)	2	2	2	2
Collective Training required in Facility 1 (days)	7	7	7	-
Collective Training required in Facility 2 (days)	-	14	14	-
Collective Training required in Facility 3 (days)	-	-	-	14
Logistic supplies required type ABC (tons)	1000	1000	1000	-
Logistic supplies required type D (tons)	-	-	-	2000
Production Rate Log Supplies ABC (tons/day)	60			-
Production Rate Log Supplies D (tons/day)	-	-	-	40
Readiness Target (days)	15	50	50	50

2.1 SOLUTION CONSTRAINED SOLELY BY LOGISTICS

6. As formulated above the regeneration is constrained solely by the rate of logistic supply and the problem can be solved quite simply as shown in Table 2. Logistics are supplied to units A, B and C sequentially. Without logistics it can be seen that all the units would meet their readiness targets but that the logistics constraint causes unit A to be late. This tests that the programme can deal with the simplest constraint type, with conflicts between units and with units that cannot meet their readiness target.

7. When dealing with this constraint, the programme needs to treat the Logistics Supplies as a Critical Task, which leads to each of the units being ready. The duration of the supply of logistics is critical to the process. Therefore, for each of the units, the amount of Logs supplies needs to be calculated, and a duration for this process needs to be defined. An alternative is to treat the Logistics supply as a resource, with each unit requiring a certain number of days/hours of work from the logistics source, and the programme needs to then level any resource conflicts. This would also involve the need to set supply priorities on each of the units. For example unit A would have highest priority, and would be supplied first.

TABLE 2 SOLUTION CONSTRAINED SOLELY BY LOGISTICS

	DAYS ON WHICH ACTIVITY TAKES PLACE						
	Recall	Individual Training	Equipment Repair	Equipment Modification	Collective Training		Ready
					Fac 1	Fac 2	
A Men	1-7	-	-	-			
A OK Equip	-	-	-	1-2	8-15	-	15
A U/S Equip	-	-	1-5	6-7			
A Supplies							1-16.7
B Men	1-7	8-21	-	-			
B OK Equip	-	-	-	1-2	22-28	29-42	42
B U/S Equip	-	-	1-5	6-7			
B Supplies							16.7-33.3
C Men	1-7	8-21	-	-			
C OK Equip	-	-	-	1-2	22-28	29-42	42
C U/S Equip	-	-	1-5	6-7			
C Supplies							33.3-50
D Men	1-7	8-21	-	-			
D OK Equip	-	-	-	1-2	22-35 (Fac 3)		35
D U/S Equip	-	-	1-5	6-7			
D Supplies							1-50

2.2 SOLUTION WITH LOGISTICS AND TRAINING CONSTRAINTS

8. The logistic constraint is a simple one in that supplies are treated as being produced continuously at a given daily rate. Thus the time required is simply the demand divided by the production rate. Introducing constraints on individual and collective training capacities further complicates the solution by introducing constraints that produce cliff edge effects. It is assumed that units B and C can give individual training to 400 men at a time. Thus unit C will have to run two sequential refresher training courses of 14 days. The first of these will train 400 men and the second 100 men. The total duration will thus be 28 days for unit C refresher training, whereas treating this as simple constraint of the previous logistic production type would lead to a duration of just over 17 days (125% of 14 days). Similarly unit D is assumed to be able to train 300 men at a time and will need to run two sequential courses of respectively 300 and 100 men.

9. The sequence with which units undertake collective training at facilities 1 and 2 is immaterial, but each training facility is assumed to be able to deal with no more than one unit at a time.

10. As discussed above the constraints on individual training impose an additional delay on unit C of 14 days and result in unit C failing to meet its readiness target. The constraint on collective training that has been introduced does not come into play because units A, B, and C become available for collective training at different times (days 8, 22 and 36 respectively) and their requirements can be de-conflicted.

TABLE 3 SOLUTION CONSTRAINED BY LOGISTICS AND TRAINING

	DAYS ON WHICH ACTIVITY TAKES PLACE						
	Recall	Individual Training	Equipment Repair	Equipment Modification	Collective Training Fac 1	Collective Training Fac 2	Ready
A Men	1-7	-	-	-			
A OK Equip	-	-	-	1-2	8-15	-	15
A U/S Equip	-	-	1-5	6-7			
A Supplies							1-16.7
B Men	1-7	8-21	-	-			
B OK Equip	-	-	-	1-2	22-28	29-42	42
B U/S Equip	-	-	1-5	6-7			
B Supplies							16.7-33.3
C Men	1-7	8-21 (400) 22-35 (100)	-	-			
C OK Equip	-	-	-	1-2	36-42	43-56	56
C U/S Equip	-	-	1-5	6-7			
C Supplies							33.3-50
D Men	1-7	8-21 (300) 22-35 (100)	-	-			
D OK Equip	-	-	-	1-2	36-49 (Fac 3)		49
D U/S Equip	-	-	1-5	6-7			
D Supplies							1-50

11. To use the software for this sort of constraint, it becomes necessary to separate the units into blocks of the correct amount to fill the Facilities. For example unit C is separated into two units, one of one hundred, and one of three hundred. These two units then call upon the same facility as a resource. As a result of this, more resource conflicts occur, which ms be levelled by the programme. However, this method will cause problems, as the size of the units may not be ideal for later stages in the process. For example, if another training course were to be added, which took less than 300 men, the units would need to be reduced again.

12. The only real alternative is to break the units down into small blocks, of say, ten men, and a proportional number of equipments. These units then call on a part of the facilities, and the programme would have to use up the resources until filled. This involves calculating the amount of work this proportionally small block would require of each available resource. This is acceptable with a simple problem such as this, but if the problem were much larger, for example, 10000 men, you would require 1000 of such blocks, which may become too cumbersome for this method to have any real value.

2.3 SOLUTION WITH WORKSHOP, LOGISTICS AND TRAINING CONSTRAINTS

11. Introducing workshop capacities does not introduce a different type of constraint, but does serve to further complicate the example problem. It also shows that dealing with cascades of fixed duration delays will rapidly expand the size of the problem. Assumed workshop capacities are defined in Table 4, it is assumed that one team can only work on one equipment at a time. Thus to repair the 20 unserviceable equipments in unit A will take twice the time required for each equipment, i.e. 10 days. Dealing with this type of constraint requires dividing the equipments into groups no larger than the constrained capacity. Thus in this example each unit's equipments must be subdivided into 10 groups each of 10 equipments.

TABLE 4 WORKSHOP CONSTRAINTS

UNIT	NUMBER OF REPAIR TEAMS	NUMBER OF MODIFICATION TEAMS
A	10	10
B	10	10
C	10	10
D	5	10

12. Table 5 shows the result of introducing the above workshop constraints. It will be noted that there is surplus capacity for modification that cannot be used for units B and C because of the throughput from their repair workshops and that unit A's repair workshop is only occupied for ten days. Units A and B are now much delayed although unit B still meets its readiness target.

13. To replicate this process with the programme, a similar method, and therefore problem, is faced as in the solution with Logistics and Training. The units would need to be broken down into smaller blocks which can at any one time fill the capacity of the workshops. The method will work, but once again may be of little value for larger problems.

TABLE 5: SOLUTION CONSTRAINED BY WORKSHOPS, LOGISTICS AND TRAINING

	DAYS ON WHICH ACTIVITY TAKES PLACE						
	Recall	Individual Training	Equipment Repair	Equipment Modification	Collective Training Fac 1	Collective Training Fac 2	Ready
A Men	1-7	-	-	-			
A OK Equip	-	-	-	1-16 (8x2 days)	21-27		27
A U/S Equip	-	-	1-10 (2x5days)	17-20 (2x2 days)			
A Supplies							1-16.7
B Men	1-7	8-21	-	-			
B OK Equip	-	-	-	1-12 (6x2 days)	43-49	23-36	49
B U/S Equip	-	-	1-20 (4x5 days)	13-14, 15-16 17-18, 21-22			
B Supplies							16.7-33.3
C Men	1-7	8-21, 22-35	-	-			
C OK Equip	-	-	-	1-10 (5x2 days)	36-42	43-56	56
C U/S Equip	-	-	1-25 (5x5 days)	11-12, 13-14, 15-16, 21-22, 26-27			
C Supplies							33.3-50
D Men	1-7	8-21, 22-35	-	-			
D OK Equip	-	-	-	1-14 (7x2 days)	36-49 (Fac 3)		49
D U/S Equip	-	-	1-30 (6x5 days)	15-16, 17-18 21-22, 26-27, 31-32			
D Supplies							1-50

2.4 SOLUTION WITH POOLING OF WORKSHOPS, LOGISTICS AND TRAINING CONSTRAINTS

13. To reduce the regeneration time of unit A the surplus capacity for modification work and the one day slack in the readiness of unit B can be exploited by transferring equipment between workshops. Transportation assets are required for this and there is a time penalty for the moves. Table 6 defines these transport times, it is further assumed that there are ten equipment transport vehicles and that equipments must be returned to their parent unit. This introduces a number of difficult scheduling problems for the software to solve and furthermore the complexity would have been considerably increased had not the transport capacity been set equal to the workshop capacities.

14. Fitting the constraint of Transport to the programme is difficult. The first problem is that the programme has no ability to make optimising decisions, as such, it needs to be told that it is quicker to transit to a different workshop, than to remain at the units' home bases. As a result of this, the only real way to indicate transit is to add it as an event, or task, and add its duration to the overall process. The other problem which arises is that of making the transit a resource, as it cannot be used by more than one unit at a time.

TABLE 6: EQUIPMENT TRANSPORT TIMES BETWEEN WORKSHOPS

UNIT	A	B	C
A	-	1 day	2 days
B	1 day	-	1 day
C	2 days	1 day	-

15. Table 6.7 shows the utilisation of the workshops and transportation assets that can be achieved and which lead to the result shown in table 8. There are a number of solutions that lead to the same overall result which provides a further test of the robustness of the software. It will be noted that, although units A and C do not meet their readiness targets, the readiness of unit A has been much improved without adverse impact on the other units.

TABLE 7:UTILISATION OF WORKSHOPS AND EQUIPMENT TRANSPORT

DAY	REPAIR WORKSHOPS(*)			MODIFICATION WORKSHOPS (*)			TRANSPORT
	A	B	C	A	B	C	(**)
1	*A*		*C*	A	B	C	*A to B*
2	*A*	*A*	*C*	A	B	C	A to B
3	*A*	*A*	*C*	A	A	C	A to C
4	*A*	*A*	*C*	A	A	C	A to C
5	*A*	*A*	*C*	A	B	A	A from B
6		*A*	*C*	A	B	A	A to B
7		*B*	*C*	A	A	C	A from C
8		*B*	*C*	A	A	C	A from C
9		*B*	*C*	A	*A*	C	A from B
10		*B*	*C*	A	*A*	C	*B to A*
11	*B*	*B*		*A*	B	C	*A from B*
12	*B*	*B*		*A*	B	C	*B to C*
13	*B*	*B*	*B*		*B*	*C*	*C to A*
14	*B*	*B*	*B*		*B*	*C*	*C to A*
15	*B*	*B*	*B*		B	*C*	*C to B*
16	*C*	*B*	*B*	*B*	B	*C*	
17	*C*	*C*	*B*	*B*	*B*		
18	*C*	*C*	*C*		*B*	*B*	*B from A*
19	*C*	*C*	*C*		B	*B*	
20	*C*	*C*	*C*		B		*B from C*
21		*C*	*C*	*C*	B		
22			*C*	*C*	B		
23					*C*	*C*	*C from A*
24					*C*	*C*	*C from A*
25							*C from B*

(*) letters refer to the unit owning the equipment italics indicates equipment that was U/S
(**)the first letter indicates the unit owning the equipment the second the unit owning the workshop thus (A to B) indicates movement of unit A equipment to unit B's workshop.

TABLE 8: SOLUTION CONSTRAINED BY SHARED WORKSHOPS, LOGISTICS AND TRAINING

	DAYS ON WHICH ACTIVITY TAKES PLACE										
	Recall	Individual Training	Equipment Repair in workshop (*)			Equipment Modification in workshop (*)			Collective Training		Ready
			A	B	C	A	B	C	Fac 1	Fac 2	
A Men	1-7	-	-	-	-	-	-	-	13-19		19
A OK Equip	-	-	-	-	-	1-10	2/3-4/5 6/7-8/9	3-4/5-6/7-8			
A U/S Equip	-	-	*/1-5/*	1/2-6/*	-	*/11-12/*	*/9-10/11	-			
A Supplies											1-16.7
B Men	1-7	8-21	-	-	-	-	-	-	43-49	23-36	49
B OK Equip (60)	-	-	-	-	-		1-2, 5-6 11-12, 15-16 19-20, 21-22				
B U/S Equip	-	-	10/11-15/*	7-11 12-16	12/13-17/*	*/16-17/18	13-14 17-18	*/18-19/20			
B Supplies											16.7-33.3

	DAYS ON WHICH ACTIVITY TAKES PLACE										
	Recall	Individual Training	Equipment Repair in workshop (*)			Equipment Modification in workshop (*)			Collective Training		Ready
			A	B	C	A	B	C	Fac 1	Fac 2	
C Men	1-7	8-21 22-35	-	-	-	-	-	-			
C OK Equip 50	-	-	-	-	-	-	-	1-2, 3-4 7-8, 9-10 11-12	36-42	43-56	56
C U/S Equip	-	-	13-14/16-20/*	15/17-21/*	1-5, 6-10 18-22	*/21-22/23-24	*/23-24/25	13-14, 15-16 23-24			
C Supplies											33.3-50
D Men	1-7	8-21 22-35	-	-	-	-	-	-			
D OK Equip	-	-				1-14 (Workshop D)			36-49 (Fac 3)		49
D U/S Equip	-	-	1-30 (Workshop D)			15-16, 17-18, 21-22, 26-27, 31-32					
D Supplies											1-50

(*)entries with the form x/y/z indicate movement of equipment (x & z) as well as repair or modification times (y). Thus for example: serviceable equipment from unit A is moved to modification workshop B on day 2, modified on days 3 & 4 and returned to unit A on day 5.

2.5 SOLUTION USING SYMANTEC◆ TIMELINE®

16. The example problem was used as a test of the TIMELINE software. The resource constraints were devised to show the limitations of software against increasingly intricate allocation and scheduling problems. The expectation was that the workshop, logistics and training constraints could be handled by low cost project management software but that the introduction of pooling of workshops with its attendant transportation sub-problem would be to cumbersome and too complex to be competently handled by such software.

17. These expectations were proven wrong. Actually, TIMELINE found a better solution than the one described in Table VIII. The programming and data entry requirements were fairly modest, approximately 8 hours of work. Note, however, that the software test was carried out by an experienced user of TIMELINE.

18. The solution procedure using TIMELINE is straight forward, until the introduction of the workshop constraint. At this stage, vehicles were divided into explicit groups of 10 vehicles (or, in the case repair at unit D, 5 vehicles)

19. The next complication is pooling of workshops. At this stage:

- equipment modification activities and repair activities were assigned as equally as possible among the facilities of A, B and C
- repair activities for equipment of unit A were given precedence over those for B, and those for B were given precedence over those for A.
- for equipment requiring both repair and modification, the repair associated activity and the associated modification activity for each such group of vehicles was explicitly linked,
- the problem formulated thus far was "solved" without regard for the transportation sub-problem
- the list of repair and modification activities was augmented with a list of transportation activities that would be required to implement it
- a transport assignment was constructed by using a truck assignment heuristic:

start with truck1 on day 1 and assign transportation activities to it until no more can be feasibly assigned; then,

add truck2 starting on day 1 and assign transportation activities to it until no more can be feasibly assigned;

continue adding trucks in this fashion until all transportation activities have been assigned to a truck.

- the overall problem was then re-solved with the transportation sub-problem feasibly embedded within it.

20. In this way, TIMELINE found a solution that is 5 days shorter that the one found by inspection. Unit A is ready in 17 days as opposed to 19, Unit B is ready in 44 days as opposed to 49 and Unit C is ready in 51 days as opposed to 56. The details of this solution are given in Tables 9 - 12.

21. The truck assignment heuristic finds that 4 trucks are required to carry out all of the transportation activities. However, it is evident from Tables 9-12 that after day 3, "truck4" is not required.

22. It is also evident, that if Units A, B and C are willing to trade equipment then one transit event for each truck can be eliminated and the response time can be reduced to the original goals of 15 days for Unit A, 42 days for Unit B and 50 days for Unit C.

Table 9: TIMELINE solution for Unit A

TASK	RESOURCES	START ON	END ON	DURATION
UNIT A		1	17	17
RECALL		1	7	7
recall A	unit A	1	7	7
COLLECTIVE TRAINING		11	17	7
collective training A @ 1	unit A, facility 1	11	17	7
Unit A Ready		18	17	0
EQUIPMENT REPAIR		1	10	10
MODIFY OK EQUIPMENT		1	8	8
MODIFY OK EQUIP	mod shop A	1	2	2
MODIFY OK EQUIP	mod shop A	3	4	2
MODIFY OK EQUIP	mod shop A	5	6	2
MODIFY OK EQUIP	mod shop A	7	8	2
transport A to B	truck1	1	1	1
MODIFY OK EQUIP	mod shop B	2	3	2
transport B to A	truck1	4	4	1
transport A to B	truck3	3	3	1
MODIFY OK EQUIP	mod shop B	4	5	2
transport B to A	truck1	6	6	1
transport A to B	truck2	5	5	1
MODIFY OK EQUIP	mod shop B	6	7	2
transport B to A	truck1	8	8	1
transport A to C	truck2	1	2	2
MODIFY OK EQUIP	mod shop C	3	4	2
transport C to A	truck2	7	8	2
REPAIR THEN MODIFY OTHER EQUIP		1	10	10
repair A equip	repair shop A	1	5	5
modify A equip	mod shop A	9	10	2
transport A to B	truck3	1	1	1
repair A equip	repair shop B	2	6	5
modify A equip	mod shop B	8	9	2
transport B to A	truck1	10	10	1

Table 10: TIMELINE solution for Unit B

TASK	RESOURCES	START ON	END ON	DURATION
UNIT B		1	44	44
RECALL		1	7	7
recall B	unit B	1	7	7
INDIVIDUAL TRAINING		8	14	7
individual training B	unit B	8	14	7
COLLECTIVE TRAINING		24	44	21
collective training B @ 1	facility 1, unit B	38	44	7
collective training B @ 2	unit B, facility 2	24	37	14
Unit B ready		45	44	0
EQUIPMENT REPAIR		2	23	22
MODIFY OK EQUIPMENT		2	21	20
MODIFY OK EQUIP	mod shop B	10	11	2
MODIFY OK EQUIP	mod shop B	16	17	2
MODIFY OK EQUIP	mod shop B	20	21	2
transport B to C	truck1	2	2	1
MODIFY OK EQUIP	mod shop C	5	6	2
transport C to B	truck1	17	17	1
transport B to C	truck2	6	6	1
MODIFY OK EQUIP	mod shop C	7	8	2
transport C to B	truck1	15	15	1
transport B to A	truck2	10	10	1
MODIFY OK EQUIP	mod shop A	15	16	2
transport A to B	truck2	18	18	1
REPAIR THEN MODIFY OTHER EQUIP		2	23	22
repair B equip	repair shop B	17	21	5
modify B equip	mod shop B	22	23	2
transport B to A	truck2	9	9	1
repair B equip	repair shop A	16	20	5
modify B equip	mod shop A	21	22	2
transport A to B	truck3	23	23	1
transport B to A	truck3	2	2	1
repair B equip	repair shop A	11	15	5
modify B equip	mod shop A	17	18	2
transport A to B	truck1	21	21	1
transport B to C	truck3	4	4	1
repair B equip	repair shop C	6	10	5
modify B equip	mod shop C	11	12	2
transport C to B	truck2	15	15	1

Table 11: TIMELINE solution for Unit C

TASK	RESOURCES	START ON	END ON	DURATION
UNIT C		1	51	51
RECALL		1	7	7
recall C	unit C	1	7	7
INDIVIDUAL TRAINING		8	21	14
individual training C	unit C	8	14	7
individual training C	unit C	15	21	7
COLLECTIVE TRAINING		22	51	30
collective training C @ 1	facility 1, unit C	22	28	7
collective training C @ 2	facility 2, unit C	38	51	14
Unit C ready		52	51	0
EQUIPMENT REPAIR		1	20	20
MODIFY OK EQUIPMENT		1	14	14
MODIFY OK EQUIP	mod shop C	1	2	2
MODIFY OK EQUIP	mod shop C	9	10	2
MODIFY OK EQUIP	mod shop C	13	14	2
transport C to A	truck2	3	4	2
MODIFY OK EQUIP	mod shop A	11	12	2
transport A to C	truck2	13	14	2
transport C to B	truck1	11	11	1
MODIFY OK EQUIP	mod shop B	12	13	2
transport B to C	truck1	14	14	1
REPAIR THEN MODIFY OTHER EQUIP		1	20	20
repair C equip	repair shop C	1	5	5
modify C equip	mod shop C	15	16	2
repair C equip	repair shop C	11	15	5
modify C equip	mod shop C	17	18	2
transport C to B	truck1	3	3	1
repair C equip	repair shop B	7	11	5
modify C equip	mod shop B	14	15	2
transport B to C	truck1	16	16	1
transport C to B	truck3	5	5	1
repair C equip	repair shop B	12	16	5
modify C equip	mod shop B	18	19	2
transport B to C	truck1	20	20	1
transport C to A	truck4	1	2	2
repair C equip	repair shop A	6	10	5
modify C equip	mod shop A	13	14	2
transport A to C	truck2	16	17	2

Table 12: TIMELINE solution for Unit D and Logistics

TASK	RESOURCES	START ON	END ON	DURATION
UNIT D		1	46	46
RECALL		1	7	7
recall D	unit D	1	7	7
INDIVIDUAL TRAINING		8	21	14
individual training D	unit D	8	14	7
individual training D	unit D	15	21	7
COLLECTIVE TRAINING		33	46	14
collective training D @ 3	unit D, facility 3	33	46	14
EQUIPMENT REPAIR		1	32	32
MODIFY OK EQUIP		1	14	14
modify OK D equip	mod shop D	1	14	14
REPAIR THEN MODIFY OTHER EQUIP		1	32	32
repair D equip	repair shop D	1	5	5
modify D equip	mod shop D	15	16	2
repair D equip	repair shop D	6	10	5
modify D equip	mod shop D	17	18	2
repair D equip	repair shop D	11	15	5
modify D equip	mod shop D	19	20	2
repair D equip	repair shop D	16	20	5
modify D equip	mod shop D	21	22	2
repair D equip	repair shop D	21	25	5
modify D equip	mod shop D	26	27	2
repair D equip	repair shop D	26	30	5
modify D equip	mod shop D	31	32	2
		1	50	50
Logistic Supplies				
logistic supplies A	log a/b/c supply	1	16	16
logistic supplies B	log a/b/c supply	17	33	17
logistic supplies C	log a/b/c supply	34	50	17
logistic supplies D	log D supply	1	50	50

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ANNEX V READINESS OF A NATO FORMATION

1 MARITIME TASK FORCE

1. The example for the calculation of required readiness levels for a formation is an example of the deployment of a maritime task force consisting of a US carrier battle group (CVBG), a UK Antisubmarine Warfare (ASW) carrier group (CVS), the Standing Naval Force Atlantic (SNFL), and two amphibious groups, one the US Marine Expeditionary Force (MEF) II, and the second the UKNL amphibious group. The breakdown of each of the task groups is given below in Table 1. The selection of ship class and ship name (pennant number) is totally arbitrary and for sake of demonstration purposes only. In this way, it was possible for the database to assign particular range and speed figures, which have been extracted from Jane's Fighting Ships, edition 1994-1995.

Table 1: Breakdown of Task Groups

Task Group	Nation ID	Ship Class	Task	Speed	Range	Pennant
CVBG	US	HENRY J KAISER	AO	18	6000	T-AO 190
CVBG	US	NIMITZ	CV	30		CVN 71
CVBG	US	BELKNAP	CG	14	8000	CG 26
CVBG	US	LONG BEACH	CGN			CGN 9
CVBG	US	ARLEIGH BURKE	DDG	20	4400	DDG 51
CVBG	US	OLIVER HAZARD	FFG	20	4500	FFG 28
CVBG	US	LOS ANGELES	SSN			SSN 704
CVBG	US	BUTTE	AE	18	10000	AE 34
CVBG	US	BLUE RIDGE	LCC	16	13000	LCC 20
CVBG	US	LOS ANGELES	SSN			SSN 706
CVS	UK	OL	AO			A 122
CVS	UK	TYPE 42 BATCH 2	DD	18	4000	D 92
CVS	UK	DUKE	FFG	15	7800	F 233
CVS	UK	INVINCIBLE	CVS	18	5000	R 06
SNFL	PO	VASCO DA GAMA	FFG	18	4900	F 331
SNFL	SP	BALEARES (F 70)	FFG	20	4500	F 74
SNFL	GE	BREMEN	FFAH	18	4000	F 211
SNFL	UK	DUKE	FFG	15	7800	F 229
SNFL	CA	HALIFAX	FFAH	15	7100	F337
SNFL	US	ARLEIGH BURKE	DDG	20	4400	DDG 52
SNFL	NO	OSLO	FFA	15	4500	F 304
SNFL	NL	KORTENAER	FFAH	16	4700	F 824
UKNLAMPH	UK	SIR BEDIVERE	LSL	15	8000	L 3036
UKNLAMPH	UK	SIR GALAHAD	LSL	15	13000	L 3005
UKNLAMPH	UK	SIR BEDIVERE	LSL	15	8000	L 3505
UKNLAMPH	UK	FEARLESS	LPD	20	5000	L 11
UKNLAMPH	NL	AMPHIBIOUS	LSL	14	6000	
USMEF	US	ANCHORAGE	LSD	12	14800	LSD 38
USMEF	US	AUSTIN	LPD	20	7700	LPD 4
USMEF	US	ANCHORAGE	LSD	12	14800	LSD 39
USMEF	US	IWO JIMA	LPH	20	10000	LPH 7

2. For each of the task groups, a fictitious begin location was chosen, in order to simulate movement times to the area of deployment. The begin location for each of the Task Groups is given below in Table 2.

Table 2 Location of the Task Groups

Task Force	Task Group	Location
TF2	SNFL	BALTIC SEA
TF2	CVBG	OFF NORFOLK
TF2	CVS	CHANNEL
TF2	UKNLAMPH	NORTH SEA
TF2	USMEF	OFF NORFOLK

2 ACTIVITIES AND PREDECESSOR RELATIONS

3 In order for the task force to constitute a viable deterrent and fighting force, certain elements had to be deployed in the contingency area before other would arrive. Typically, the CVBG group would escort the MEF II. The SNFL would be in place quickly to show presence and deter any initial aggression. A precursor operation would be performed by the CVS group to ensure the safety from submarine attacks on the aircraft carrier. Table 3 provides details on the activities and the precedence relations between the activities.

Table 3: Activities

Task Force	Activity	Task Group	Type of Activity	Predecessor 1	Predecessor 2	Predecessor #3
TF2	Sailing SNFL	SNFL	Movement	Ready SNFL		
TF2	Ready USMEF	USMEF	Ready at location	Start		
TF2	Sailing USMEF	USMEF	Movement	Ready USMEF		
TF2	Sailing USMEF 2	USMEF	Movement	Sailing USMEF		
TF2	Sailing USMEF 3	USMEF	Movement	Sailing USMEF 2		
TF2	Ready UKNL	UKNLAMPH	Ready at location	Start		
TF2	Sailing UKNL	UKNLAMPH	Movement	Ready UKNL		
TF2	Start	CVBG	Preparation			
TF2	Ready CVBG	CVBG	Ready at location	Start		
TF2	Sailing CVBG	CVBG	Movement	Ready CVBG		
TF2	Ready CVS	CVS	Ready at location	Start		
TF2	Sailing CVS	CVS	Movement	Ready CVS		
TF2	Sailing CVS 2	CVS	Movement	Sailing CVS		
TF2	Sailing CVBG 2	CVBG	Movement	Sailing CVBG		
TF2	Sailing CVBG 3	CVBG	Movement	Sailing CVBG 2		
TF2	Sailing CVBG 4	CVBG	Movement	Sailing CVBG 3		
TF2	Workup CVBG	CVBG	Preparation	Sailing CVBG 4	Sailing USMEF 3	Sailing SNFL
TF2	Workup CVS	CVS	Preparation	Sailing CVS 2	Sailing UKNL	
TF2	Precursor Ops	CVS	Operation	Workup CVS		
TF2	Deployed All	CVBG	Operation	Workup CVBG	Precursor Ops	
TF2	Ready SNFL	SNFL	Ready at location	Start		

4 In order to calculate the critical path for the above activities, expected times of duration of each of the activities has to be established. Readiness of the forces may be a given, or the method may identify critical paths which are modified accordingly to get better results and meet the required deployment date. Durations of operations are also estimated, as well as movement. Since the speed of the slowest vessel in the task group is given, and the distance between the peacetime location and the deployment area can be calculated, movement times can be assessed easily. Thus the movement activities are assigned expected movement times. A stylised ocean and sea map is envisioned providing the various distances between oceanic areas and seas. Table 4 provides details on the timings of the activities and additional information on the various legs of the sailings of the task groups.

Table 4 Timings for Activities

Task Force	Activity	Task Group	Type of Activity	Expected Time	Shortest	Longest	Begin	End
TF2	Sailing SNFL	SNFL	Movement	4.4	3.8	5	BALTIC SEA	NORWEGIAN SEA
TF2	Ready USMEF	USMEF	Ready at location	5	5	6	---------	---------
TF2	Sailing USMEF	USMEF	Movement	3.1	2.5	4.2	OFF NORFOLK	OFF HALIFAX
TF2	Sailing USMEF 2	USMEF	Movement	5.6	4.5	7.5	OFF HALIFAX	GIUK GAP
TF2	Sailing USMEF 3	USMEF	Movement	4.7	3.8	6.3	GIUK GAP	NORWEGIAN SEA
TF2	Ready UKNL	UKNLAMPH	Ready at location	5	5	6	---------	---------
TF2	Sailing UKNL	UKNLAMPH	Movement	4.7	3.8	5.4	NORTH SEA	NORWEGIAN SEA
TF2	Start	CVBG	Preparation	0	0	0	---------	---------
TF2	Ready CVBG	CVBG	Ready at location	5	5	5	---------	---------
TF2	Sailing CVBG	CVBG	Movement	3.3	2.2	4.6	OFF NORFOLK	WESTLANT
TF2	Ready CVS	CVS	Ready at location	5	4	7	---------	---------
TF2	Sailing CVS	CVS	Movement	1.5	1.4	1.7	CHANNEL	NORTH SEA
TF2	Sailing CVS 2	CVS	Movement	4.4	4.2	5	NORTH SEA	NORWEGIAN SEA
TF2	Sailing CVBG 2	CVBG	Movement	3.3	2.2	4.6	WESTLANT	EASTLANT
TF2	Sailing CVBG 3	CVBG	Movement	3.9	2.5	5.4	EASTLANT	GIUK GAP
TF2	Sailing CVBG 4	CVBG	Movement	3.9	2.5	5.4	GIUK GAP	NORWEGIAN SEA
TF2	Workup CVBG	CVBG	Preparation	4	3	5	---------	---------
TF2	Workup CVS	CVS	Preparation	2	2	3	---------	---------
TF2	Precursor Ops	CVS	Operation	2	2	4	---------	---------
TF2	Deployed All	CVBG	Operation	2	2	4	---------	---------
TF2	Ready SNFL	SNFL	Ready at location	2	2	3	---------	---------

3 CRITICAL PATH METHOD (CPM) RESULTS

5. Subsequently, results can be calculated using the Critical Path Method (CPM). Thus for each activity, the earliest start and end, and the latest start and end is assessed, the activities are ordered, and the slack, which is the difference between either earliest start and latest start, or earliest end and latest end, is calculated. Those activities that have zero slack, belong on the critical path.

6. The example results are given in Table 5. We see that the activities of the CVBG belong on the critical path. Thus better results for the required deployment date are to be get by shortening the readiness criteria for the CVBG. However, since the US MEF II has only slightly less available slack (0.6 days), savings in time can only be found by taking into account this marine force also.

Table 3.1: Results

Task Force	Activity	Duration	Variance	Earliest Start	Earliest End	Latest Start	Latest End	Slack
TF2	Start	0	0	0	0	0	0	0
TF2	Ready CVBG	5	0	0	5	0	5	0
TF2	Ready CVS	5.2	1.0	0	5.2	7.9	13.0	7.9
TF2	Ready SNFL	2.2	0.6	0	2.2	13.0	15.1	13.0
TF2	Ready UKNL	5.2	0.6	0	5.2	9.1	14.3	9.1
TF2	Ready USMEF	5.2	0.6	0	5.2	0.6	5.8	0.6
TF2	Sailing CVBG	3.4	0.9	5	8.4	5	8.4	0
TF2	Sailing CVBG #2	3.4	1.8	8.4	11.7	8.4	11.7	0
TF2	Sailing CVBG #3	3.9	2.7	11.7	15.6	11.7	15.6	0
TF2	Sailing CVBG #4	3.9	3.6	15.6	19.5	15.6	19.5	0
TF2	Sailing CVS	1.5	1.3	5.2	6.7	13.0	14.5	7.9
TF2	Sailing CVS #2	4.5	1.8	6.7	11.1	14.5	19.0	7.9
TF2	Sailing SNFL	4.4	1.2	2.2	6.5	15.1	19.5	13.0
TF2	Sailing UKNL	4.7	1.3	5.2	9.8	14.3	19.0	9.1
TF2	Sailing USMEF	3.2	1.3	5.2	8.4	5.8	9.0	0.6
TF2	Sailing USMEF 2	5.8	2.2	8.4	14.1	9.0	14.7	0.6
TF2	Sailing USMEF 3	4.8	3.1	14.1	18.9	14.7	19.5	0.6
TF2	Workup CVBG	4	4.4	19.5	23.5	19.5	23.5	0
TF2	Workup CVS	2.2	2.3	11.1	13.3	19.0	21.2	7.9
TF2	Precursor Ops	2.3	3.1	13.3	15.6	21.2	23.5	7.9
TF2	Deployed All	2.3	5.2	23.5	25.8	23.5	25.8	0

ANNEX VI

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